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Abstract

This report summarizes discussions from the Mission Critical Voice Virtual Roundtable hosted by the Public Safety Communications Research (PSCR) Division of the National Institute of Standards and Technology (NIST) in April 2024. PSCR convened 37 first responders and communications engineers from across the United States, representing diverse public safety disciplines. Discussions focused on the current state of mission-critical voice communications, challenges faced by first responders, and the transition to and integration of new technologies. The report also details subsequent deep dive conversations with an expanded set of first responders at the 5x5 Public Safety Innovation Summit, held in June 2024.

Keywords

Interoperability, technology, land mobile radio (LMR), broadband, public safety, communication, roundtable, push-to-talk (PTT)

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1. Introduction

The Public Safety Communications Research (PSCR) division of the National Institute of Standards and Technology (NIST) is committed to understanding and evolving public safety communications through internal and external research, stakeholder engagement, and standards development. The Mission Critical Voice (MCV) portfolio within PSCR focuses on research related to voice communications for first responders, primarily through the internally developed Quality of Experience (QoE) metrics. The environment surrounding voice communications for first responders has continually evolved since the inception of the MCV portfolio in 2017. To account for those changes, the portfolio team held a roundtable to engage with mission-critical voice stakeholders and subject matter experts.

The Mission Critical Voice Virtual Roundtable (Roundtable) was held during the week of April 29, 2024. The Roundtable was intended to validate the current MCV QoE Key Performance Indicators (KPI), discuss the current state of mission-critical voice, understand how PSCR's MCV Portfolio can drive research to benefit public safety, and determine where the next generation of mission-critical communications is headed. The Roundtable served as the first phase of a two-phased approach to interact with public safety stakeholders to determine the most significant issues for mission-critical communications in the eyes of first responders. The second phase of stakeholder interaction involved taking three topics that received a wide variety of feedback during the Roundtable and developing them into three deep dive sessions in order to address the topics with a wider variety of participants. These sessions took place during the 5x5 Public Safety Innovation Summit held in Chicago, IL during the week of June 25, 2024. This document describes the development, execution, and outcomes derived from the Roundtable and subsequent engagements.

1.1. Background of PSCR and the MCV Portfolio

The PSCR MCV Portfolio is a comprehensive initiative spearheaded by NIST to research the capabilities and reliability of public safety voice communications. It is part of the broader PSCR effort to improve communication technologies used by first responders. As such, the Roundtable was an important step toward understanding public safety's existing technologies and concerns surrounding existing and future technologies. The primary goals for these discussions included:

- **Characterizing Communications:** Understanding the current state of, and future concerns associated with, mission-critical communications for public safety.
- **Improving Communication:** Facilitating seamless mission-critical communications across agencies and jurisdictions.
- **Supporting Innovation:** Encouraging the development of new technologies and methods to improve public safety communications.

To develop research in mission-critical communications, the MCV team identified four main topic areas relevant to public safety. The following list describes those topics and how they relate to the work performed in the MCV portfolio:

- **Mission-Critical Push-to-Talk (MCPTT):** Development of research into optimizing voice communications for enhanced intelligibility and reliability utilizing mission-critical applications specific to public safety.
- **Quality of Experience (QoE):** Collaboration with public safety to define KPIs and develop a set of metrics that provide a quantitative measurement to ensure that voice communications remain clear and effective even in challenging environments.
- **Interoperability:** Identification of gaps and issues in existing communication systems and developing solutions to ensure seamless integration and collaboration across diverse platforms.
- **Next-Generation Networks:** Exploration of the implications and benefits of transitioning to next-generation push-to-talk (PTT) technologies and other forward-looking technologies for enhancing public safety communications.

The MCV portfolio addresses several challenges, including the need for systems that function reliably with varying levels of coverage and extreme operating conditions, integration of new technologies with existing infrastructure, and the continuous evolution of communications standards.

In addition to the work described above, the scope of the MCV portfolio involves collaboration with various stakeholders including public safety agencies, technology developers, and industry experts. This collaboration ensures that research and development efforts are aligned with the real-world needs of first responders and other public safety personnel. By focusing on these areas, the MCV portfolio aims to provide public safety professionals with tools and technologies they need to perform their duties more effectively. This task includes ensuring that communication systems are resilient in emergencies, enabling efficient coordination during incidents, and supporting overall public safety and emergency response efforts.

The MCV portfolio represents a vital component of ongoing efforts to advance public safety communications. By addressing the technical, operational, and interoperability challenges associated with mission-critical voice communications, NIST supports first responders with the tools and standards necessary to enhance their effectiveness and safety.

1.2. MCV QoE KPI Framework from 2017 Roundtable

The central focus of the MCV portfolio's research is effective communication for public safety, especially during emergencies where timely and clear information can significantly impact outcomes. The following KPIs were identified during a previous mission-critical voice roundtable held in 2017 and were later developed into quantifiable metrics supporting MCV research. These KPIs are essential for evaluating the quality of a first responder's experience using PTT communication systems in public safety settings. They provide public safety agencies

with valuable insights into the reliability and intelligibility of their voice communications, as well as how system latency affects overall effectiveness. The MCV QoE KPIs are defined as:

- **Mouth-to-Ear (M2E) Latency:** The amount of time it takes for speech input in a voice communication transmit device to be heard on the receiving device once the communications channel is established.
- **End-to-End Access Time:** The amount of time to establish a talk path upon a user's request to speak, comprising the time from pressing the PTT button to the receiving user hearing intelligible voice.
- **Voice Quality & Intelligibility:** The clarity and understandability of the transmitted voice. This KPI focuses on how well the message is conveyed and understood, which is critical for preventing misunderstandings in high-stress situations. High intelligibility ensures that communication remains effective and accurate for emergency response scenarios.
- **Probability of Successful Delivery (PSuD):** The likelihood that a message will be successfully delivered and understood by the receiving user. This KPI evaluates message transmission effectiveness in two contexts: when every word is critical and when some context is available given the current situation of the incident.

One of the goals of this Roundtable was to revisit these KPIs and evaluate whether changes or advancements to PTT communications since 2017 have impacted their relevance. To maintain the integrity of future MCV research, KPIs should accurately represent the performance of communication systems as they evolve.

2. Development of the Roundtable

Since the initial roundtable in 2017, the landscape of public safety communications has expanded. Broadband networks specifically for first responders have been created, applications for mission-critical PTT over broadband have been developed, and land mobile radios (LMRs) are incorporating broadband and cloud connectivity to augment their existing communications. Given the continuing evolution of the environment for public safety communication, first responders needed a sustained dialogue with MCV researchers to provide feedback to improve voice communication technologies. Although in-person meetings were possible, due to the dynamic nature of first responder schedules and because PSCR wanted to talk with the widest variety of first responders possible, the MCV team ultimately chose to conduct the Roundtable as a virtual venue.

2.1. Roundtable Design

PSCR originally defined the program's focus as research related to the communications of first responders in mission-critical environments, specifically, law enforcement, fire services, and emergency medical services. These were the primary groups that the MCV team hoped to engage during this Roundtable. Due to the significance of radio engineering and the optimization of communication platforms in mission-critical voice research, radio communications engineers and dispatchers were also added to the groups of interest during the Roundtable meeting design discussions. During the development of the Roundtable structure, the team wanted to ensure that all disciplines were able to convey their concerns equally, without overrepresenting any one group. That consideration, combined with the varied nature of voice communications the different first responder groups, led the team to develop a structure that gave each group a chance to voice their concerns independently and then come together at the end to identify areas of commonality between the disciplines represented in the Roundtable. To support these discussions, the final structure of the event was as follows:

- **Day 1:** Discussion with Radio Communications Engineers
- **Day 2:** Discussion with Fire Service and EMS
- **Day 3:** Discussion with Law Enforcement
- **Day 4:** Discussion with all participants on common areas of interest

2.2. Anticipated Outcomes of the Roundtable

The MCV team had several motivations for re-engaging with first responders at this time. With the public safety community integrating broadband communications into their existing systems, the team looked to ensure that the original KPIs still accurately defined a first responder's QoE. Additionally, the team wanted to understand how public safety concerns relating to their communications have changed with the introduction of new technologies. The following sections outline the intended outcomes of the Roundtable.

2.2.1. Evaluating the Landscape of Public Safety Voice Communications

The MCV team gathered insights into the changes observed in public safety from a "boots on the ground" perspective. They assessed the current prevalence of broadband communications and explored intentions to adopt these technologies in the future. Additionally, the team gained an understanding of why departments choose to incorporate broadband into their mission-critical communications and how enhancements being made to LMR systems were being utilized in practice.

2.2.2. Understanding Quality Concerns from an Operational Perspective

The MCV team wanted to identify specific quality issues encountered during mission-critical voice communications, the root causes of these problems, and the additional resources required to address them. By gaining insight into the concerns of first responders, the team developed research that could address and mitigate these issues. One of the key concerns during the roundtable was that of interoperability, and understanding how LMR and broadband interworking affected a first responder's voice communication experience. Using this understanding, the MCV team developed a project specifically examining the impacts of LMR / Broadband interworking on QoE. Furthermore, understanding the operational challenges helped the team evaluate the relevance of the original QoE KPIs established in 2017 in the context of today's challenges.

2.2.3. Understanding the Challenges for Next-Generation Communications

The introduction of broadband technologies into the mission-critical first responder environment provides both the opportunity for optimizing voice communications and a springboard for leveraging data-centric communications, such as video, sensors, and other data-driven technologies. Although the research is still in the early phases, the MCV team seeks to understand the perception of those technologies in first responder communities and identify any high-level concerns that could direct future research in Mission Critical Services (MCS).

2.2.4. Identifying Topics for Further Discussion during the 5x5 Stakeholder Conference

The Roundtable was designed to provide several topics that could be utilized as deep dive discussions during the 5x5 Stakeholder Conference, to be held in Chicago, IL, in June 2024. The team chose the selected topics for their relevance to public safety participants. The MCV team wanted to leverage the wider audience of the 5x5 platform to explore topics that required more insight.

3. Roundtable Discussions

The Roundtable was held during week of April 29th, 2024. Discipline-specific breakouts were held from April 29 to May 1, and a final session comprised of all disciplines was held on May 3, 2024. To facilitate discussion, the PSCR MCV team developed a series of questions to gather information pertaining to the outcomes described in Section 2.2. In addition to verbal discussion, the MCV team developed a series of interactive polls to allow all participants to provide feedback regardless of their ability to speak within the group. This section summarizes the outcomes of all four Roundtable sessions.

3.1. Participants

This Roundtable was by invitation only and featured 37 participants in various disciplines and support roles and members of the PSCR team. The following table provides a list of all participants of the four sessions, their public safety organizations, and their affiliations.

Table 1. Table Listing of MCV Roundtable Participants, Disciplines, and Affiliations

Name	Organization	Affiliation
Rocco Baldino	Washington DC Fire & EMS Department	Fire and EMS
Scott Barthelmass	Eureka Fire Protection District	Fire
Marc Biundo	Washington State Patrol	Law Enforcement
Peter Burke	Hyannis Fire	Fire and EMS
Adam Burns	City of Boulder Integrated Radio System	Radio Comms
Julia Chelen	UI/UX Research Engineer	PSCR
Hunter Culler	MCV Research Engineer	PSCR
Jason Day	Texas Department of Public Safety	Law Enforcement
Joe Duvall	Dallas, GA Police	Law Enforcement
Peter Fink	MCV Research Engineer	PSCR
Sterling Folden	Mountain View Fire	Fire
Kerianne Gibney	Strategic Engagement Program Manager	PSCR
Red Grasso	State of North Carolina Department of Info Tech	Radio Comms
Kyle Green	Fire Marshall University Fire Department - Fairbanks, AK	Fire
Patrick Hagan	Houston Fire	Fire

Pete Hallenbeck	Orange Rural Fire Department	Fire
Charlsea Hansen	MCV Research Engineer	PSCR
Gary Howarth	MCV Research Engineer	PSCR
David Jackson	Kansas City Police Department	Law Enforcement
Buddy Jacob	Boise Fire Department	Fire
Alison Kahn	MCV QoE Project Lead	PSCR
Jarod Koon	Ellettsville Police Department	Law Enforcement
Charles Laird	State of North Carolina Department of Info Tech	Radio Comms
Ken Link	Monroe Township Fire District-NJ, FEMA USAR NJ-TF1	Fire
Hien Nguyen	MCV Research Engineer	PSCR
Jordan O'Dell	MCV Research Engineer	PSCR
Chayne Pieri	Houston Fire - IT dept (Tech Spec/Analysis)	Fire
David Povlitz	Arlington Fire	Fire
Robert Putfark	Arvada Fire Protection District	Fire
Ryan Putman	Utah State Fire Marshall	Fire
Sam Ray	MCV Research Engineer	PSCR
Paul Roberts	Boise Fire Department	Fire
James Shultz	Houston Fire - COML/COMT	Fire
Lisa Soucy	MCV Portfolio Lead	PSCR
Niels Tangherlini	San Francisco Fire	Fire
Scott Whitehead	Boulder County Sheriff's Office	Radio Comms
Gregory Williams	Kansas City Police Department	Law Enforcement

The participants included engineers from PSCR as well as radio communications engineers, fire service professionals, law enforcement officers, and emergency medical services officers from across the U.S. Participants held various ranks within their respective disciplines and provided unique perspectives due to differences in discipline, rank, position, and operating environment. Figure 1 provides a representative breakdown of the participants with respect to their public safety disciplines.

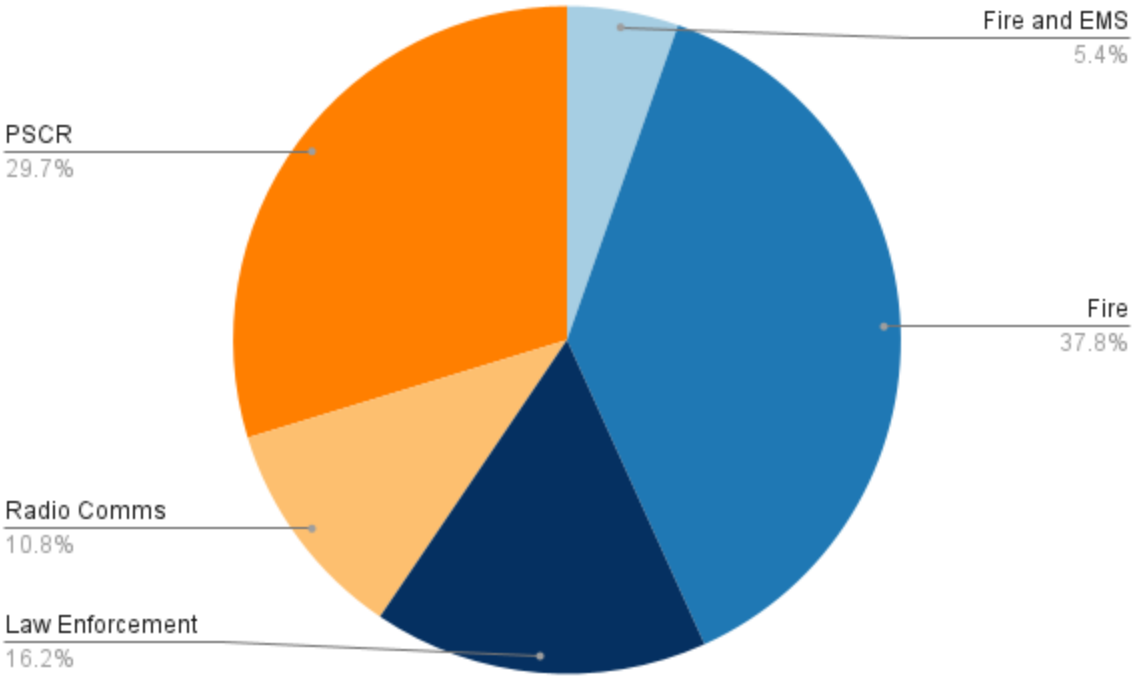

Fig. 1. Affiliation breakdown of participants at the Mission Critical Voice Virtual Roundtable

3.2. Day 1: Radio Communication Engineers

During the first Roundtable session, the MCV team spoke with radio communications engineers from several public safety agencies across the country to understand their concerns with radio performance. Feedback from this sector was important because they represent the individuals tasked with optimizing communications networks for first responders in their divisions; consequently, they are aware of problems across systems as they arise and are responsible for working to overcome the issues experienced by the first responders. Participants in the discussion highlighted several key points regarding public safety communications, particularly focusing on the transition from traditional LMR systems to broadband technologies. Figure 2 depicts the wide variety of responses received from the engineers when asked about details regarding the networks—whether broadband carrier networks, LMR core networks, or other communication systems—used during their departments' operations.

Fig. 2. Responses to "What carrier network/LMR core provider/other network do you use for your communications?"

Participants emphasized the complexities and challenges associated with integrating multiple communication tools from different vendors and/or carrier-specific offerings into a cohesive system. This integration often leads to confusion among users and necessitates comprehensive training to ensure effective use. Voice quality issues on the networks leading to degraded audio were a significant concern within public safety. The primary factors contributing to poor voice quality were environmental conditions, user equipment, and network infrastructure. Participants stressed the importance of addressing these issues to maintain clear and reliable communication, especially in critical situations.

Participants were then asked how often their voice communications were deemed insufficient, and the responses were recorded via group polling, shown in Figure 3. According to the poll, most problems were experienced between 1% and 25% of the time, with some participants experiencing issues up to 50% of the time. No responses indicated a level of insufficiency beyond that point.

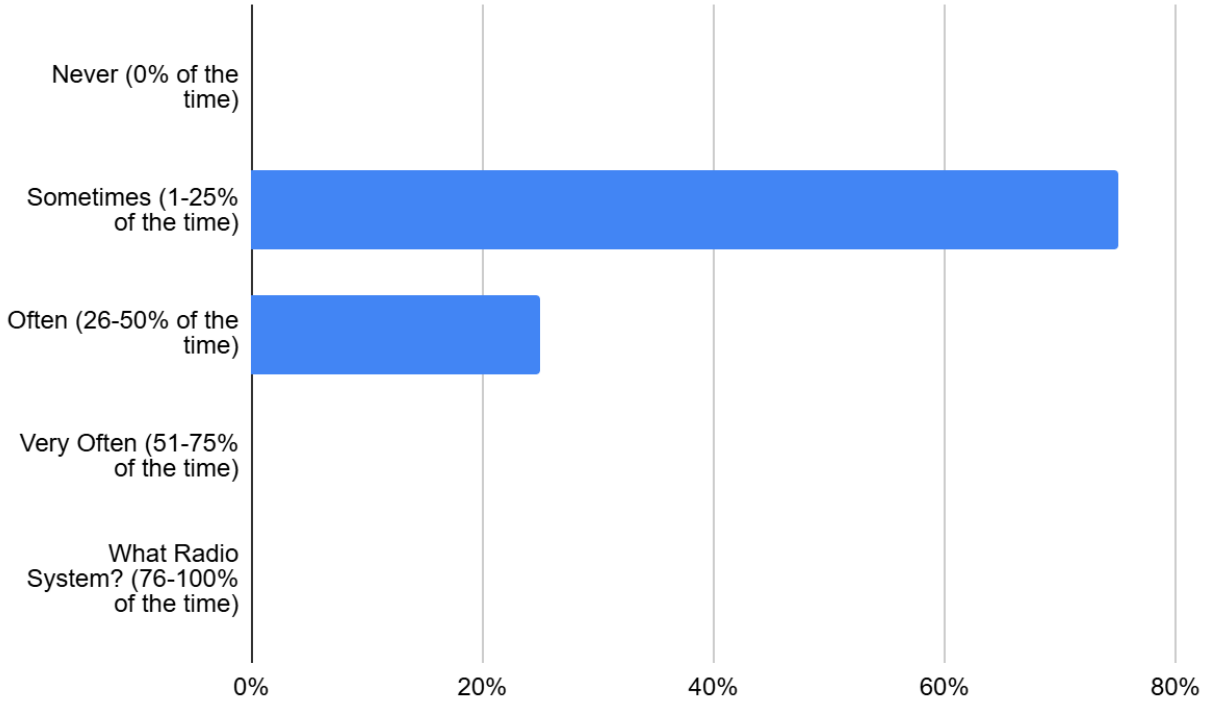

Fig. 3. Responses to "How often does your department experience inadequate communications?"

Participants were then asked to identify factors that contributed to the issues described in the previous question. Group polling allowed participants to select an answer from general areas including "Environment," "User Equipment," "Network Equipment," and "Operational Concerns." Participants were also given the option to select "Other" for factors that did not fit into any of the other general areas. Figure 4 summarizes the factors discussed by participants as affecting their communications in the field.

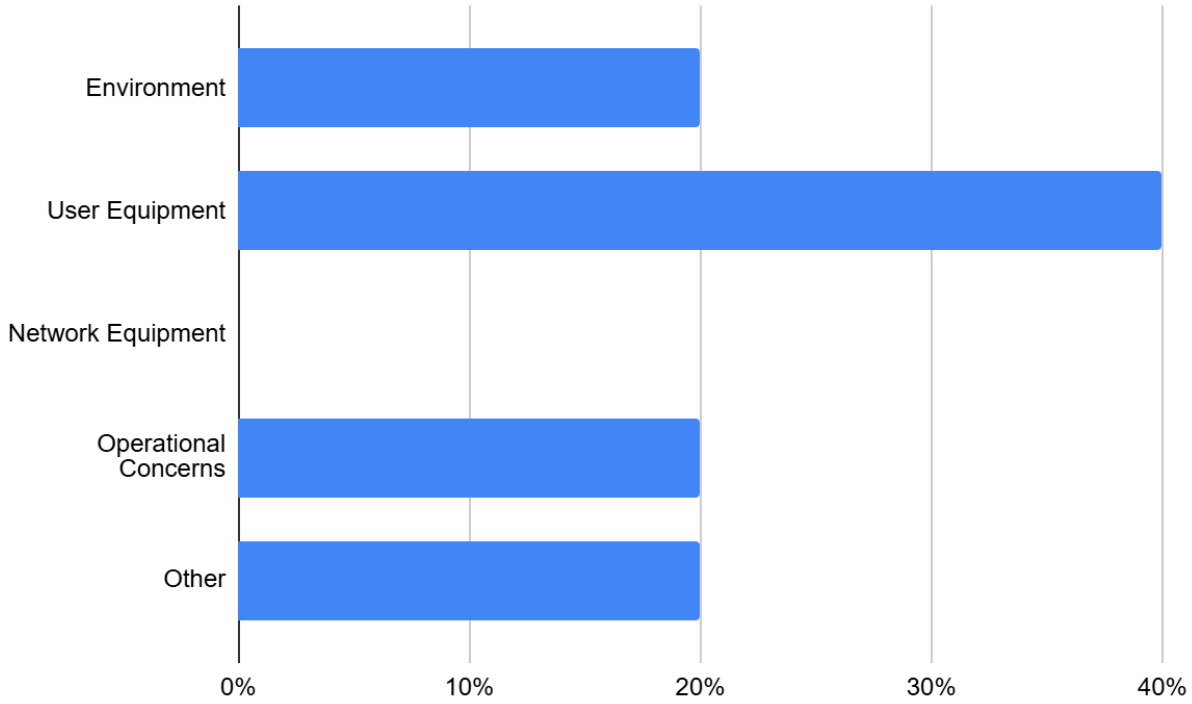

Fig. 4. Responses to "What is the biggest factor contributing to communications issues in your department?"

Many factors contributed to the issues experienced by participants, with user equipment being the most cited issue. The conversation touched on the need for standardization in public safety communication technologies. Inconsistent implementations of Bluetooth and LTE standards between public safety vendors and applications pose challenges for interoperability and reliability. Anti-competitive practices by some system manufacturers further complicate efforts to develop and implement standardized solutions.

Participants highlighted the importance of system management and coordination for ensuring effective communication. Pre-planning and anticipating the communication needs of different divisions, such as SWAT teams and fire departments, were deemed essential. Participants gave examples of successful storm response modes and the importance of having robust communication plans, such as an Incident Radio Communications Plan (*ICS 205*)[1], in place. Participants also discussed the transition to broadband technologies and associated infrastructure limitations. They mentioned need for direct mode and higher power levels in broadband devices, along with the potential for broadband devices to incorporate feature functionality similar to traditional LMR solutions. The conversation also covered the challenges of maintaining and optimizing devices, including firmware updates, noise canceling, and

[1] FEMA, ICS Form 205: Incident Radio Communications Plan (Version 3.1) (Emergency Management Institute, 2021), https://training.fema.gov/emiweb/is/icsresource/assets/ics%20forms/ics%20form%20205,%20incident%20radio%20communications%20plan%20(v3.1).pdf

automatic gain control (AGC). The transition of emergency features such as emergency buttons and user IDs from LMR to broadband communications was another area of concern. Participants emphasized the expectation that all communication applications should support emergency features consistently to ensure user safety.

3.3. Day 2: Fire Service/Emergency Medical Services

The Roundtable session on day two captured the experiences of professionals from the fire service and emergency medical services (EMS). These two professions were combined, as firefighters are often also certified emergency medical technicians (EMTs) and there is a close working relationship between the two roles. Discussions focused on the transition from traditional LMR systems to broadband networks and the use of MCPTT applications as supplemental communication methods. As in the first session, participants were asked how often they experienced inadequate communications where messages could not be fully received. Figure 5 shows the responses from the fire service/EMS group.

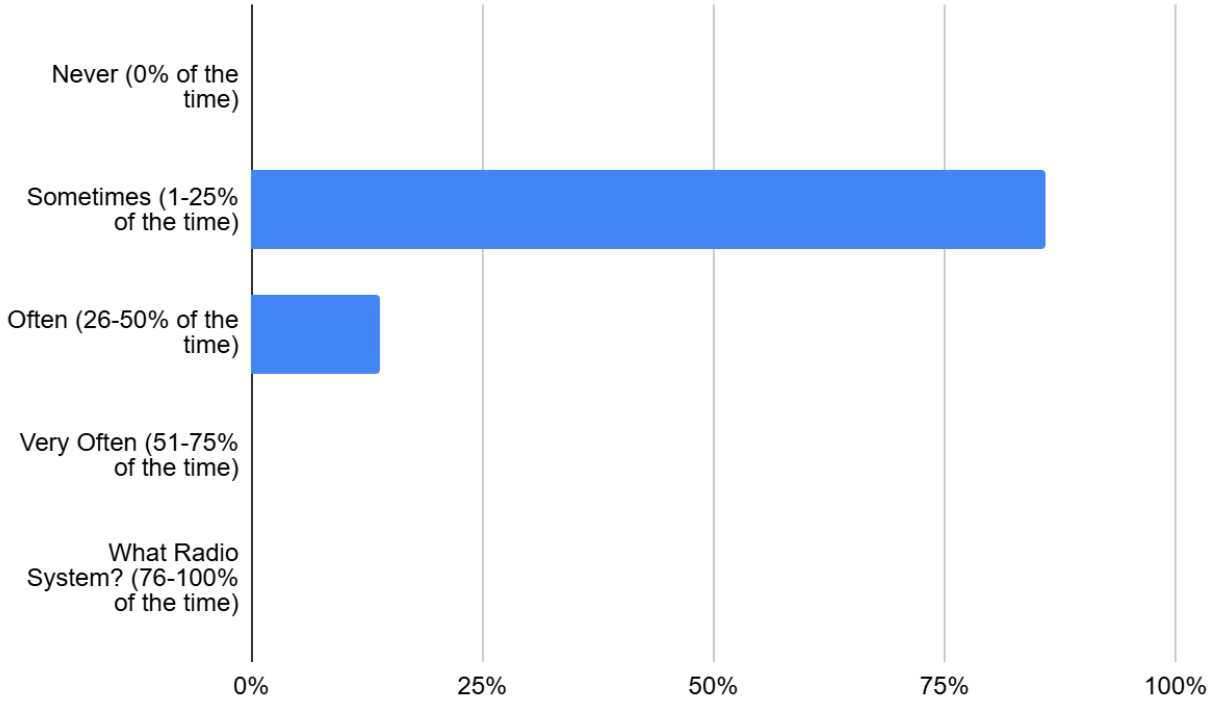

Fig. 5. Responses to "How often do you experience what you would call inadequate communications?"

As with the radio communications engineers in the previous session, firefighters and EMS participants did not report experiencing severely impacted communications on a regular basis. Instead, most respondents felt that they experienced impacted communications up to 25% of the time.

As participants discussed the current state of their mission-critical communications, the conversation naturally shifted to the topic of how broadband communications could be used alongside LMR communications. As the discussion evolved, participants were asked specifically what features broadband communications applications lacked when comparing them to LMR communications. Figure 6 shows the answers provided by the participants in word cloud format.

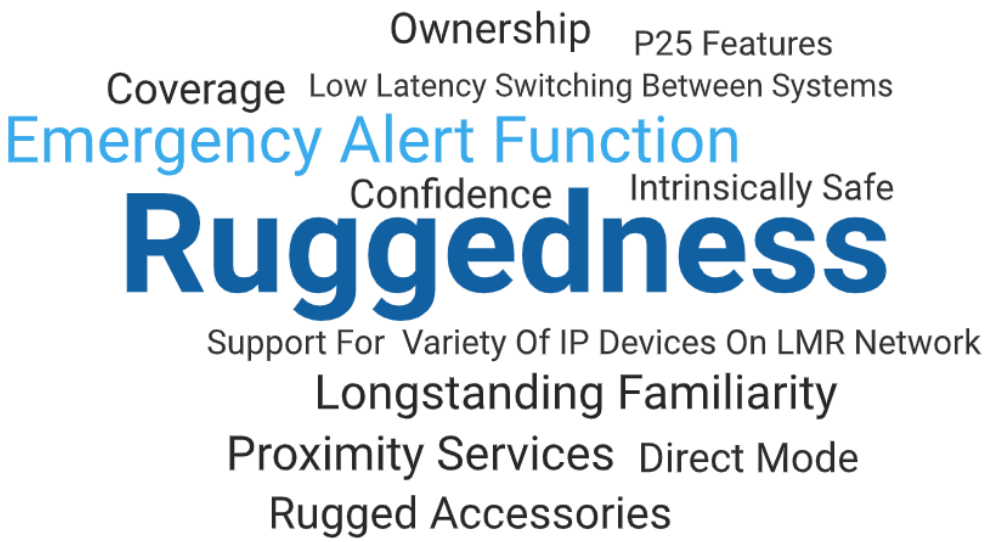

Fig. 6. Responses to "What is broadband lacking compared to LMR?"

Challenges such as the lack of standardization in emergency alerting and the need for rugged and user-friendly devices were discussed. The participants' perspectives also indicated that broadband devices features and applications need to mimic more comprehensively the features of traditional LMR radios. Compatibility between different communication platforms and devices was also highlighted.

When looking toward the future of their voice communications, participants emphasized the importance of LMR features such as LMR-broadband interoperability solutions for maintaining connections in disrupted environments. The potential of low-earth orbit (LEO) satellites for backhaul in rapid deployable communication systems was discussed, particularly for improving coverage in rural areas. The use of High-Power User Equipment (HPUE) to augment broadband coverage was also mentioned.

The discussions highlighted decision-making processes within public safety agencies, driven by financial constraints, operational needs, and staffing levels. The need for better communication solutions in emergency situations was emphasized, from both technology and usability perspectives. Participants discussed the use of vendor-specific radios and features and the importance of emergency button functions in MCPTT applications. This feedback underscored

the role of the PSCR program in providing research updates and driving the development of new technologies tailored to the needs of public safety agencies.

3.4. Day 3: Law Enforcement

The third discipline-specific day of the Roundtable was focused on law enforcement. The discussion with law enforcement provided perspectives regarding concerns of their discipline, including the augmentation of traditional LMR systems through interoperability with broadband communication technologies. Discussions centered on the shift to broadband technologies, highlighting the benefits of improved coverage and cost savings. Participants emphasized the importance of reliable communication tools in critical situations, particularly with respect to implementation of mission-critical communication applications on broadband networks and understanding the user interfaces of these applications and the performance with respect to coverage and mission-critical features. The challenges of interoperability and multi-jurisdiction responses were also key topics, with a focus on the need for standardized procedures and the ease of connectivity provided by broadband devices.

Law enforcement provides some of the highest-profile examples of complete transitions to broadband PTT communications, and the team was interested in learning more about how these implementations were being supported. To that end, network usage was a prime topic for the conversation. Figure 7 shows attendee responses to the question of network provider usage within the department.

Fig. 7. Responses to "What carrier network/LMR core provider/other network do you use for your communications?"

As shown by the word cloud above, law enforcement participants were the heaviest broadband network users, and the Roundtable questions drilled further into how they utilized these networks. The discussions underscored the importance of interoperability, user feedback, and continuous research to optimize communication strategies for first responders. The session provided a law enforcement perspective on the evolving landscape of public safety communications, highlighting the challenges, solutions, and future directions. The conversations emphasized the need for a "killer app" to drive the adoption of broadband technologies in public safety and explore the potential benefits of cost savings and improved

coverage with these systems. Although broadband networks create the benefit of data driven applications, having multiple applications to interface with will reduce the responder's ability to process the data for effective situational awareness. A "killer app" would not only bring voice, text, and image communications, to a single access point, but it would be able to make appropriate decisions for the first responder based on the information provided. Additional discussions with participants highlighted the potential of mesh networks and artificial intelligence (AI) to further extend the network and provide situational awareness and decision-making in bandwidth-constrained environments.

3.5. Day 4: All Disciplines

The final Roundtable discussion brought together representatives from all public safety disciplines to explore the evolving landscape of next-generation mission-critical communications. A key focus was on the use of drones and real-time video in mission-critical environments. Structural firefighters currently leverage drones equipped with heat-sensing technology to detect heat signatures within buildings, while wildland firefighters utilize fire detection cameras. However, the practical application of drones in wind-driven wildland fires poses significant challenges. Law enforcement reported using video-capable drones for monitoring remote areas and emphasized the importance of a stable internet connection to push the information where it could be properly reviewed. This was a common theme for technologies focused on the future: as public safety increasingly relies on data-intensive applications, maintaining knowledge of the network's strength and connection status at all times is critical.

Because of the larger audience and varied opinions from having all public safety disciplines present on the fourth day of the Roundtable, the PSCR team relied heavily on polls and open-text responses through group polling, in addition to verbal discussions. This approach allowed all participants to contribute to the conversation in the manner with which they were most comfortable. It also kept the meeting timeline manageable while allowing the team and participants to follow up on key topics of discussion.

The discussion on mission-critical communications focused on the essential requirements for MCPTT solutions, particularly concerning voice intelligibility, latency, and resiliency. With all disciplines represented, the team wanted to underscore the participants' perception of performance in mission-critical broadband PTT systems. The word cloud in Figure 8 shows the participants' responses to the question, "What does a mission-critical PTT solution need to provide to meet the needs of public safety?"

Fig. 8. Responses to "What does a mission-critical PTT solution need to provide to meet the needs of public safety? "

Responses underscored the need for interoperability across devices, applications, and networks, along with challenges posed by improper accessories such as off-the-shelf microphones. Participants emphasized the importance of local ownership of communication networks to ensure reliability and control during critical incidents. Of the features generated by the word cloud, the participants were then asked to rank the top features from most important to least important. The team wanted to ensure that the rankings reflected the previous responses and provided further detail on the needs of first responders.

Figure 9 shows the responses to the mission-critical feature importance ranking. As the chart demonstrates, “Intelligibility” and “Resiliency/Reliability” tied for the highest ranking, with “Interoperability” coming in just beneath them.

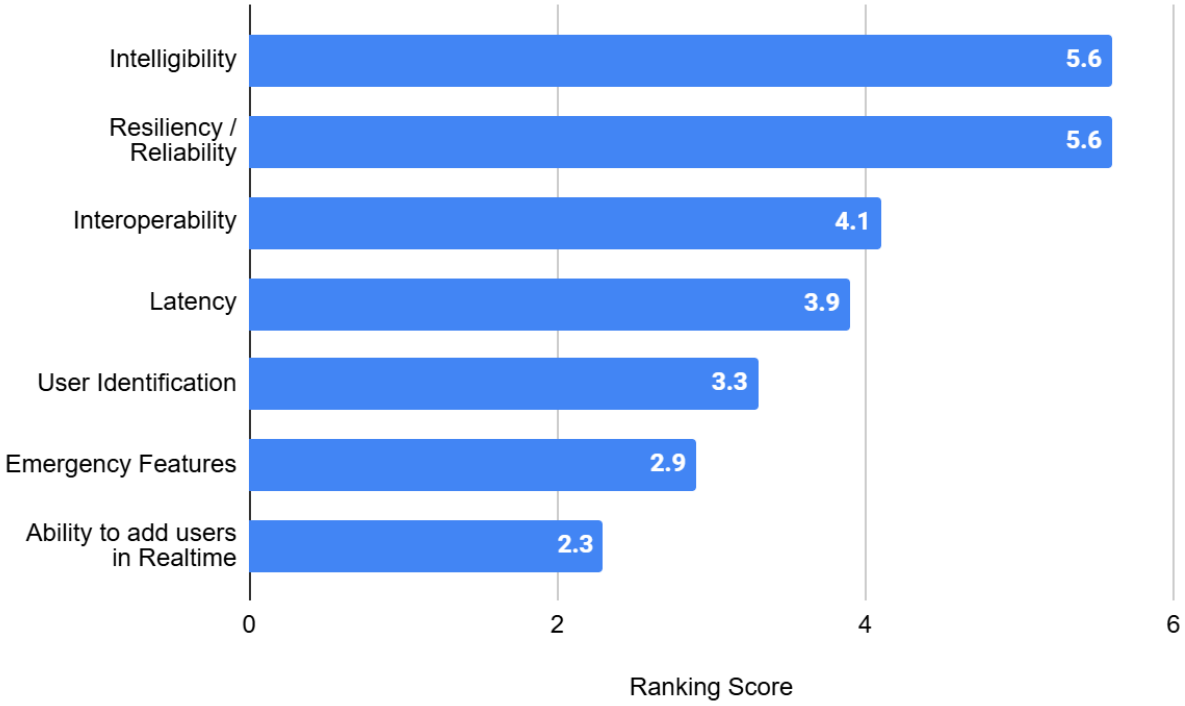

Fig. 9. Mission-critical feature importance (most important to least).

Additionally, the participants discussed newly implemented technologies in the context of mission-critical communications, such as Bluetooth and Wi-Fi, raising concerns about their reliability and potential vulnerabilities in mission-critical environments. While Bluetooth offers wireless convenience, participants noted issues like interference and additional failure points. Mesh networks and satellite technology offer potential solutions to improve communication in remote or challenging environments, though variable propagation of the communications channels and the resulting latency remain significant hurdles. The TAK software application suite provides data-sharing capabilities, although challenges in customization and integration persist.

To gain a better understanding of current challenges faced in mission-critical communication, participants discussed several targeted questions and were given the opportunity to provide answers in open text or verbal feedback during the discussions. Those answers and discussions are summarized below.

During the Roundtable, participants discussed when they noticed voice and performance degradation, such as intelligibility, latency, or resiliency issues during mission-critical events. Key issues identified included weak simplex (device-to-device) connections due to building layouts, limited bandwidth and channel availability from backhaul constraints, and improperly configured LMR vehicle repeater systems. Participants noted challenges like poor or inconsistent coverage, particularly in buildings and high-noise situations. Additional concerns included LMR performance degradation during large-scale events and interference from

external signals, such as 10,000 citizens all trying to use Wi-Fi and cellular devices alongside public safety communications.

The conversation continued with participants discussing techniques they use to mitigate these types of issues. Participants revealed various strategies for enhancing voice intelligibility, latency, and resiliency in communication systems. Many participants utilize multiple cellular providers for redundancy and employing over-the-top applications to reduce network dependency. HPUE technology is deployed to boost broadband connectivity, especially in vehicle-mounted setups. Participants discussed ongoing concerns about Wi-Fi usage for MCPTT and ongoing efforts to engage with system engineers to address latency issues. They also emphasized the importance of training responders on effective radio use, optimizing system and radio audio settings for enhanced audio quality, ensuring that responders use only authorized accessories, and advocating for layered solutions and additional tower installations.

From there, the discussion shifted slightly to a discussion of how participants interacted with interconnected primary and secondary LMR and broadband systems. Participants highlighted the current state of integration between interconnected primary and secondary networks, revealing significant separations due to funding and billing challenges. Many participants expressed concerns about relying on Wi-Fi for communications in high-density situations where performance is inconsistent. They find that LMR and priority cellular networks complement each other, and in some cases, they are awaiting FedRAMP approval for vendor-specific features to enhance integration. FedRAMP is a government-wide risk management program for cloud services, required by many public safety agencies to ensure security of their data. However, the full vetting process for new services or platforms can take time to complete. Other concerns involved testing experiences which showed that transitions from LMR to MCPTT via a gateway bridge can be slow, depending on device connectivity. The underlying technology offers seamless transitions between dual LMR and broadband devices, and some participants reported successful interactions with these features. However, participants raised concerns about certain limitations, such as the lack of audible notifications when switching between networks, making it difficult for users to determine which network is active. Overall, while some integration efforts are underway, challenges remain in ensuring reliable communication across different systems.

With the previous reference to the utilization of accessories that may impact the user's experience, the MCV team asked which audio accessories were most frequently used with PTT devices. Responses indicated a strong preference for corded accessories, such as remote speaker microphones, underscoring a desire for reliability. However, notable interest in Bluetooth options reflected a shift toward wireless technology. Participants mentioned accessories like Bluetooth handheld microphones and tactical communications devices that utilize Bluetooth for mounting on gear or vehicles, showcasing the diverse range of uses for wireless technologies.

Next, we asked participants what new public safety communications technology/products they heard of and could potentially use in their operations. The responses reflected in the word cloud in Fig. 10 highlight a range of innovative solutions that are shaping the future of public safety communications.

Fig. 10. Responses to "What new public safety communications technology/products have you heard of that you're excited about?"

From LEO satellites and mesh networks to advanced applications like TAK and AI voice optimization, these technologies promise to enhance connectivity, resilience, and operational efficiency.

When participants were asked what challenges they wanted to solve with new technology, they identified several areas, such as exploring broadband networks for LMR backhaul and collecting data on system performance in order to justify communications funding requests. The high cost of LMR equipment, particularly in non-critical environments, was a significant concern, and participants saw advanced technologies used to facilitate data transmission and optimize voice communications as a way to overcome the high costs. However, participants recognized a need for improved data interoperability before alternate forms of communication could be widely integrated to offload voice traffic.

In addition to voice and data communications, Roundtable participants emphasized the growing importance of transmitting mission-critical information through alternate means. The word cloud in Fig. 11 below shows participants' responses when asked what mission-critical information was important and could be received outside of voice communications.

Fig. 11. Responses to "What mission-critical information is important to send or receive outside of voice comms?"

Real-time video emerged as a crucial tool for various operations such as hazmat situations and situational awareness in firefighting. Participants noted differences in video usage between wildland and structural firefighting, highlighting the need for specific use cases to provide actionable insights. For instance, while real-time video might not significantly alter the immediate response in structural firefighting, it can be invaluable in wildland scenarios for assessing terrain and fire spread. The discussion also touched on the use of data and mapping systems to offload voice traffic, enhancing overall communication efficiency. Collecting data on system performance and utilization was deemed essential for stakeholder justification and continuous improvement of communication systems.

Participants spoke to the potential of AI to interpret and manage multiple video streams, facilitating rapid access to relevant information during both inspections and emergency responses. Additionally, Next Generation 911 (NG911) emerged as a significant topic, highlighting its role in incorporating multiple information streams—including social media—to enhance emergency response efforts. The system's ability to provide continuous updates throughout an incident was recognized as a major advantage, significantly improving the connection between responders and the public. Furthermore, AI's potential to assist dispatchers and officers in sorting through incoming information and recommending appropriate responses showcased its capability to navigate the complexities of modern emergency communications.

Final thoughts from the participants touched on the use of data and mapping systems to offload voice traffic, enhancing overall communication efficiency. Collecting data on system performance and utilization was deemed essential for stakeholder justification and the continuous improvement of communication systems. Voice performance degradation during mission-critical events was a recurring theme, particularly due to the use of untested or improper accessories. Efforts to improve voice intelligibility include running MCPTT alongside LMR and investigating rapidly deployable backhaul networks. The reliability of accessories like

Bluetooth devices and throat microphones was discussed, with a consensus emphasizing the need for durable, well-tested solutions.

The discussions emphasized the importance of standardized technology solutions, the integration of various communication tools, and the critical role of real-time data in enhancing emergency response capabilities.

4. Key Themes and Takeaways of the Roundtable

Throughout the conversations held on the four days of the Roundtable, various themes emerged as areas of importance to first responders and their communications counterparts. The MCV team compiled these themes to use as guides to inform research and development relating to public safety voice communications going forward. Additionally, these themes created the baseline from which the 5x5 Deep Dive topic areas were developed. The tables below categorize the themes into several generalized categories and display each theme within its own table. Each table contains a list of topics and a short description of each topic.

4.1. Mission Critical Voice Communications

Impact of Communication Systems	
Varying Nomenclatures	Different jurisdictions use different terms and communication protocols, complicating inter-agency communication during emergencies.
Training	Public safety needs consistent, adequate training and effective collaboration. A lack of these can result in issues in the field.
Case Examples	Events such as the Marshall fire and the Lahaina wildfire demonstrated how system overload and channel availability issues can severely impact response efforts.
Effective Management	Effective communication requires thorough planning, regular exercises to identify coverage gaps, and establishing a common operating picture.

Requirements for MCPTT Solutions	
Intelligibility	Clear communication is crucial in challenging environments such as those encountered when using air packs during firefighting.
Resilience	Solutions must be able to withstand interference and maintain functionality under various conditions, including extreme environmental conditions and in-building communications.
Robustness	MCPTT systems must provide clear and reliable communication, even in the most demanding situations.

Voice/Performance Degradation During Critical Events	
Performance Issues	Performance degradation often results from users employing untested accessories, such as remote speaker microphones or headsets, leading to poor audio quality.
Additional Challenges	Issues like low talkers and improper equipment use exacerbate communication problems.
Importance of Testing	Ensuring that all accessories are rigorously tested and compatible with communication systems is crucial for maintaining high-quality communication during critical events.

4.2. Radio and Network Optimization

Improving Voice Intelligibility, Latency, and Resiliency	
Using MCPTT with LMR	A common trend is integrating MCPTT alongside traditional LMR systems to address challenges with voice intelligibility and resiliency. Radios supporting broadband technology allow first responders to use one radio with both communication systems.
Local Backhaul Options	Exploring local backhaul options is vital; compact rapid deployable systems can provide on-scene support in cases where commercial options fail.
Communication Outcomes	The overarching aim is to enhance communication reliability by improving voice intelligibility, reducing latency, and increasing overall resiliency during emergencies.

Interacting with Primary and Secondary Networks	
Integration Efforts	Ensuring seamless connectivity between primary and secondary networks is crucial and involves integrating routers or network switching technologies allowing a user to utilize multiple systems with one radio.
Latency Concerns	Addressing latency issues is essential; delays during transitions between LMR and cellular networks can affect communication quality.
Importance of Seamless Switching	Maintaining effective communication relies on a system's ability to switch between networks without significant delays or loss of quality.

4.3. Integration of New Technologies

Impact of Communication Systems	
Exploration of New Technologies	Departments are actively exploring new technologies like LEO satellite and terrestrial broadband networks to enhance communication, particularly in rural areas where traditional infrastructure is limited.
Consideration of Existing Technologies	Technologies from LMR and broadband providers, both network and devices, are being evaluated based on coverage needs.
Integration Goals	The aim is to provide more flexible and robust communication options, ensuring reliable connectivity during emergencies.

Providing Research Updates to Inform Public Safety Decisions	
Role of PSCR	The Public Safety Communications Research (PSCR) program plays a vital role in supporting public safety agencies by offering timely research updates.
Content of Updates	Updates should include insights on new technologies, performance metrics, and best practices for integrating innovations into existing systems.
Impact on Decision-Making	Keeping agencies informed about the latest research helps them make better decisions regarding the adoption and implementation of new communication technologies.

Beneficial New Technologies for Public Safety Communications	
Recognized Technologies	Technologies such as LEO satellites and dual coverage radios have potential to improve communication in various environments.
Network Transition Capabilities	Technologies supporting both LMR and broadband technologies facilitate seamless transitions between different networks and enhance overall communication capabilities.
Enhanced Effectiveness	Leveraging updated network technologies such as LEO satellites and hybrid network radios allow public safety agencies to improve their communication effectiveness during emergencies, even under challenging conditions.

4.4. Challenges in Communication During Emergencies

Fallback on Broadband and Use of Apps During Emergencies	
Reliance on Broadband Connectivity	During incidents such as lithium battery fires, agencies have sometimes had to rely on broadband connectivity and regular phone calls when traditional radio systems failed.
Testing MCPTT Apps	Testing with MCPTT apps over broadband has shown promise, but challenges remain with integrating these apps into LMR networks and maintaining emergency button functionality.
Importance of Reliable Fallback	Ensuring that fallback options are reliable and effective is essential to maintain communication during emergencies.

Features Required for Broadband Devices	
Direct Mode Communication	Broadband devices must offer direct mode communication and sufficient power to match traditional radios.
Reliable Coverage	Reliable coverage and seamless integration with existing systems are critical for their adoption.
Mission-Critical Standards	Meeting these requirements ensures that broadband devices can provide the high standards needed for mission-critical communications in public safety.

Concerns with Broadband Compared to LMR Voice	
Large Scale Events	Recognizing how interoperable traffic is handled during large events and how to mitigate overload issues on those channels is crucial to ensuring that communications remain stable during high traffic events.
Understanding System Architecture	Understanding the architecture of broadband systems and ensuring that emergency buttons and user IDs are correctly mapped is necessary for users communicating between broadband and LMR networks.
Addressing Reliability Concerns	Addressing concerns regarding the reliability and functionality of broadband devices is important to ensure that broadband solutions can match the performance of traditional LMR systems.

4.5. Interoperability and Standardization

Defining Interoperability	
Definition	Interoperability involves ensuring that devices, applications, and networks work seamlessly together.
Importance of Standardization	Standardizing protocols and ensuring different systems can communicate effectively are essential for coordinated responses across multiple agencies and jurisdictions.
Impact on Emergencies	Achieving interoperability is vital for effective communication during emergencies.

Standardization in Emergency Alerting	
Critical for Communication	Standardization in emergency alerting and the integration of unique identifiers with cell phones are critical for ensuring consistent and reliable communication.
Challenges with P25 Functions	The lack of standardized P25 functions in broadband platforms remains a challenge.
Timely Response	Establishing standards for emergency alerting ensures that all agencies can receive and respond to alerts in a timely and coordinated manner.

Broadband vs. LMR Capabilities	
Ruggedness of Systems	Broadband solutions often lack the ruggedness and emergency alert functions that are standard in LMR systems.
Meeting Requirements	Ensuring that broadband devices can meet these requirements is crucial for their adoption in public safety communications.
Addressing Gaps	Addressing these gaps is necessary for ensuring that broadband solutions can provide the same level of reliability and functionality as traditional LMR systems.

4.6. Training and Collaboration

Sources of Radio Training Materials	
Development of Materials	Training materials for radio communication are often developed in-house, tailored to the specific needs of each agency.
Importance of Training	Comprehensive training is essential for ensuring that users are familiar with the capabilities of their communication devices.
Effective Use During Emergencies	Providing effective training helps ensure that personnel can operate their communication tools effectively during emergencies.

Training Frequency and Barriers to Access	
Barriers to Engagement	Participation in available training is often hindered by factors such as cost and accessibility.
Schedule Constraints	Training is often secondary to operational priorities and emergency response duties, leaving limited time for dedicated instruction
Need for Proficiency	Receiving the appropriate training is critical for ensuring that all personnel are proficient in using their communication devices and systems.

Goals for Enabling New Technologies	
Enhancing Communication	The overarching goal is to enhance communication capabilities, enabling public safety agencies to respond more effectively to emergencies.
Focus Areas	This includes improving interoperability, reliability, and overall performance of communication systems.
Equipping Personnel	By adopting new technologies, agencies aim to equip their personnel with the best tools available for managing and responding to emergencies.

5. 5x5 Discussions and Outputs

After the completion of the Roundtable, the team's next task was to determine the areas of interest for public safety and which topics would be best suited for deep dive discussions at the 5x5 Stakeholder Conference which would be held the following June. To do this, the team proposed topics relevant to the audience and applicable to future PSCR research.

5.1. Topic 1: Communications Network Evolution

This deep dive would encompass the topics of "Integration of New Technologies" and "Interoperability and Standardization," to understand how first responders viewed their voice communications networks evolving in the near future. The session, titled "Blueprints for Tomorrow's Network: Strategies to Plan for the Future of MCV," would provide insight into functions and applications that public safety targeted to implement enhanced voice communications.

5.2. Topic 2: MCPTT Device Functionality

For this deep dive, the team wanted to cover "Interoperability and Standardization" from a device perspective as well as some of the challenges with communications during emergencies (feature functionality and broadband vs. LMR capabilities). The session was titled "Future-Proofing Push-to-Talk: Key Features and Functionality for Tomorrow's MCV Applications."

5.3. Topic 3: Integration of Next-Generation Technologies

For this topic, the team aimed to look at the "Integration of New Technologies" from the perspective of next-generation technologies. We refer to "next-generation technologies" as those that are used commercially or are on the verge of being used commercially now, but that have not been fully vetted from a public safety perspective. Topics of interest would include concepts such as AI and IoT technologies, as well as real-time data for different scenarios. This session was ultimately titled "Next-Gen Services for the First Responder: How Can Public Safety Utilize New Technologies."

5.4. Deep Dive Sessions at 5x5 Public Safety Innovation Summit

The following section summarizes the sessions held during the *2024 5x5: Public Safety Stakeholder Innovation Conference*, which took place June 25-27, 2024, at the Millenium Fairmont Hotel in Chicago, IL.

5.4.1. Session 1: Blueprints for Tomorrow's Network: Strategies to Plan for the Future of MCV

This session involved a detailed discussion on public safety networks and implementation, with a focus on exploring the future of mission-critical communications. The goals of this session were to understand how current public safety networks are implemented and optimized, and

to understand the requirements needed for networks to accommodate features for future communications, such as mission-critical PTT over broadband.

The discussion emphasized the urgent need for standardized, efficient, and reliable systems, highlighting the important shift from traditional LMR technologies to more advanced, broadband-enabled solutions, such as MCPTT. The session delved into the challenges associated with this integration, particularly concerns regarding existing policies, procedures, and the readiness of current infrastructures to adapt to new standards. Participants addressed concerns around adoption of non-compliant, proprietary solutions that may lack the robustness required for mission-critical operations, potentially jeopardizing lives in emergencies due to system failures or insufficient interoperability.

The discussion also underscored the significance of adopting standardized solutions that maintain performance under the extreme demands of crisis situations. While over-the-top (OTT) proprietary applications might offer simplicity and convenience under normal conditions, their reliability and effectiveness in emergencies are questionable. The session emphasized the necessity for solutions that perform uniformly well across varying and challenging conditions.

Participants discussed the financial implications and justifications for agencies grappling with the cost of upgrading to or implementing compliant solutions. The session shed light on the dilemma faced by agencies, particularly in rural regions, where existing communication options are limited. The transition to standardized, broadband-enabled solutions presents a change both to existing financial mechanisms and operational policies for these agencies. The ability to shift from the capital expenses incurred by the local LMR implementations, which were often subsidized by grant funding, to an operating expense model varies across departments, depending on their existing funding structures.

Participants also highlighted the potential of data analytics to revolutionize system intelligibility and coverage effectiveness. They saw the ability to automate or streamline network evaluation and optimization as a benefit to incorporating broadband networks into existing mission-critical communication.

Overall, the session underlined a collective acknowledgment of the imperative to evolve, standardize, and rigorously test mission-critical communication systems. It painted a vision of a future where interoperability, clarity, and reliability are foundational elements, supported by continuous innovation and a unified approach toward adopting and enforcing standards. This deep dive into strategies for the future of mission-critical communications reflects a convergence towards a more connected, resilient, and effective emergency response framework, pivotal in safeguarding communities in times of crisis.

5.4.2. Session 2: Future-Proofing Push-to-Talk: Key Features and Functionality for Tomorrow's MCV Applications

The second session focused on PTT features and functionality, specifically what is missing and what can evolve. This topic was a high-priority outcome from the Roundtable. The session aimed to gather additional information on the key PTT features needed by public safety and the functionality required to enable successful critical communications.

In exploring the future of PTT technology within the MCV arena, the discussion highlighted several pivotal considerations aimed at ensuring these systems are future-proof. One of the foremost concerns was the necessity for next-generation PTT systems to adhere rigorously to established safety and reliability protocols, such as the NFPA 1802 standard[2] catering specifically to fire service communication devices. This standard calls for equipment that is not only rugged and able to maintain connection under extreme conditions but also simple to operate, allowing ease of use even with heavy protective gloves. The session emphasized an intuitive user interface devoid of unnecessary complexity.

The integration of broadband technology into the emergency services communication repertoire sparked a nuanced dialogue. Instead of viewing broadband as a replacement for current LMR systems, the consensus leaned toward finding harmonious ways to integrate these technologies. While broadband communications offer broader capabilities, such as enhanced data services and potentially greater coverage, LMR's proven reliability, especially in life-threatening situations, cannot be understated. The session stressed the value of developing interoperability solutions that bridge the gap between siloed LMR systems and emerging broadband platforms. It also addressed the reality that current interoperability measures are insufficient and need substantial reinforcement.

Challenges surrounding the adoption of broadband communications technologies in public safety domains were also dissected, particularly concerning device durability and operational lifespan, economic implications, and the pressing need for a public safety-specific operating system. This tailored operating system should differ fundamentally from civilian mobile operating systems, embedding features and default settings optimized for public safety use cases to ensure first responders can rely on these devices during critical operations.

The session also raised concerns about how public safety entities manage and maintain communication infrastructure, particularly in rural or economically constrained regions. The conversation hinted at the financial and operational pressures faced by smaller municipalities, pointing to the necessity for cost-effective, scalable solutions that do not compromise on quality or reliability.

The dialogue encapsulated a clear mission: to develop and deploy PTT solutions that are not just technologically advanced but also practical, reliable, and tailored to the unique demands of first responders and public safety personnel. Achieving this mission requires continuous collaboration between technology developers, standards bodies, and end users—ensuring that as we step into the future, our critical communication tools remain steadfast, supporting those who depend on them the most.

[2] National Fire Protection Association (NFPA). **NFPA 1802: Standard on Two-Way, Portable RF Voice Communications Devices for Use by Emergency Services Personnel in the Hazard Zone** (2021). Retrieved from https://www.nfpa.org/codes-and-standards/nfpa-1802-standard-development/1802

5.4.3. Session 3: Next-Gen Services for the First Responder: How Can Public Safety Utilize New Technologies

The third session focused on next-generation (Next-Gen) mission-critical services, a high-priority outcome from the Roundtable. The goal was to identify relevant Next-Gen services such as video, sensors, and AI, determine how public safety sees using these technologies operationally, and identify gaps that these technologies can fill.

The Next-Gen Services discussion for First Responders provided impactful insights into the future of public safety operations through the lens of technology integration. Central to the conversation was the exploration of how next-generation technologies can align with first responders' needs for significant enhancements in their operational effectiveness, safety, and decision-making capabilities in real-time scenarios.

The discussion focused in part on the underutilization of advanced technologies in public safety departments, with only a handful indicating plans to integrate new technology. This opened up a broader discourse on potential areas where technology could make substantial impacts beyond the traditional voice communications that have been the backbone of public safety operations. Participants highlighted the importance of enhanced monitoring systems, health trackers for first responders, and augmented communication tools in ensuring the safety and efficiency of first responders on the field. These tools not only promise to enhance operational capacity but also, critically, to predict and prevent potential health crises among first responders during missions. Further depth was added to the conversation through the lens of AI and data analytics. The discussion pointed toward a future where AI automating routine tasks, generating actionable insights from emergency calls, and even aiding in language translation. Participants viewed integration of AI as a direct response to staff shortages and operational efficiency challenges, showcasing a practical application of technology in enhancing the quality of emergency response services.

Another significant area explored was the use of video technology in public safety. This included its application in fire investigations, situational awareness during operations, and the potential for real-time video feeds to complement traditional emergency response mechanisms. Though adoption is currently limited, participants identified the profound impact of video technology, particularly in providing detailed situational analysis and supporting post-incident reporting.

The session also acknowledged challenges such as data privacy, accuracy of technological solutions, integration into existing public safety frameworks, and the need for technologies to be developed with a specific focus on public safety needs. Despite these hurdles, the direction is clear: there is a strong impetus toward embracing technology to redefine the landscape of public safety operations. The Nex-Gen Services discussion underscored an emerging consensus on the critical role of technology in the future of public safety, from enhancing the safety and operational efficiency of first responders through advanced monitoring and communication technologies to leveraging AI and video analytics.

6. Conclusion

The Roundtable and the deep dive sessions at the 5x5 Public Safety Innovation Summit provided invaluable insights into the evolving landscape of mission-critical communications. These discussions highlighted the necessity for ongoing research, innovation, and collaboration to meet the dynamic needs of public safety agencies in the face of rapid technological advancements.

The discussions illuminated the current challenges and advancements in mission-critical voice communications for public safety agencies. By tackling issues such as communication system integration, interoperability, standardization, and enhanced training, the discussions identified areas that would bolster the overall effectiveness of public safety communications. The outcomes emphasized the critical need for PSCR's continued research to ensure that public safety agencies are equipped to manage critical incidents effectively.

The MCV team remains dedicated to further research, stakeholder collaboration, and the dissemination of findings to guide future developments, ensuring that first responders have access to the most effective communication tools available.

The MCV team acquired valuable insights into the relevance of their existing metrics, even as the environment for mission-critical voice communication continues to evolve. Feedback from the public safety community confirmed that the key performance indicators (KPIs) originally identified by PSCR remain pertinent today and will continue to inform their research efforts. The MCV portfolio serves as a cornerstone of ongoing efforts to advance public safety communications. By addressing the technical, operational, and interoperability challenges inherent in mission-critical voice communications, NIST is committed to equipping first responders with the tools and standards necessary to enhance their effectiveness and safety.

Appendix A. Glossary

AGC: Automatic Gain Control
EPTT: Enhanced Push-to-Talk
EMT: Emergency Medical Technician
HPUE: High-Power User Equipment
ICS: Incident Command System
IoT: Internet of Things
KPI: Key Performance Indicators
LEO: Low-Earth Orbit
LMR: Land Mobile Radio
LTE: Long-Term Evolution
M2E: Mouth-to-Ear
MCPTT: Mission-Critical Push-to-Talk
MCV: Mission Critical Voice
NFPA: National Fire Protection Association
NIST: National Institute of Standards and Technology
OS: Operating System
OTT: Over-the-Top
PSCR: Public Safety Communications Research
PTT: Push-to-Talk
PSuD: Probability of Successful Delivery
QoE: Quality of Experience
TAK: Team Awareness Kit