Wireless Communication and Spectrum Sharing for Public Safety in the US

Introduction

In a public safety system, communication failures due to large or small-scale disasters can lead to catastrophic consequences.[1,2,3,4,5] In the United States, it is estimated that more than 50,000 state and local public safety agencies currently exist with fewer than 50 users mobilizing radio systems for wireless communication while employing approximately 1.1 million first responders.[6] The effective performance of a Public Safety Communication System (PSCS) is contingent on the availability of high capacity wireless services to emergency management personnel, first responders, and users in disaster-affected areas.[1,7] However, the utilization of today's PSCS system hinges on limited wireless technology from past decades and cannot cope with current needs.[1,8,9]

Some key challenges for a national wireless communication system of public safety include: a) innovative formation and cost-effective implementation of independent spectrum markets of heterogeneous wireless resources, b) policies and procedures to regulate and incentivize stakeholders for spectrum sharing and management, and c) realistic modeling and efficient operation of communication infrastructure within disaster-affected environments. An ideal system can improve interoperability, spectral efficiency, dependability and fault tolerance, advanced capabilities, security, and cost effectiveness.[4,9] This exploratory analysis provides an introduction into a broader research agenda of promoting a national public safety system and the strengths and challenges for implementation. The following questions will be addressed in the paper: A) What does an ideal national wireless public safety system consist of? B) What are the key policies in regulating wireless communication and spectrum sharing for public safety? And,

C) What challenges exist for implementing a national public safety wireless communication system?

Communication for Public Safety

Implementing a national public safety system centers on successful integration of diverse communication technologies, networked infrastructure, security processes, and needs of impacted communities.[1,4,5,10,11] Currently, there are a plethora of elements eligible for sharing, ranging from cellular towers to core network infrastructure and operation support systems.[12] An ideal communication system would need to achieve a balance and incorporate effective interoperability, dependability and fault tolerance as well as advanced capabilities for managing security, cost and spectral efficiency.[4,7]

Interoperability showcases the ability of individuals and organizations to communicate and disseminate information.[1,4] Impediments include funding, incompatible systems, and geographic coverage. In contrast, a purported benefit to a national system is the capability of creating a common operating picture and vocabulary for local, state and federal response agencies to support efficient wireless communication.[3] As for dependability and fault tolerance, wireless communication infrastructure and spectrum sharing policies must be able to adapt to the needs of response agencies and support operations in regards to stationary (i.e. headquarters), semi-mobile (i.e. mobile command posts) or mobile actors (i.e. frontline personnel).[13]

In terms of advanced capabilities, a challenge for emergency responders is not only providing timely and accurate information before, during and after disasters and crises, but also filtering through information and resources to minimize stress on the system.[3,13] These systems must acknowledge the voice of public safety (i.e. first responders, practitioners, researchers, community members, etc.) while also allowing for broadband data transfers, geolocation, and real-time video capabilities.[4,14] In addition, the level of security within the communication infrastructure is an indicator of an ideal system. As outlined in a White House memorandum, stakeholders must focus on safeguarding sensitive, classified, and proprietary data as well as creating a pilot program for assessment purposes of spectrum efficiency and operability.[9] In addition, Peha[4] encouraged protection against interagency communications as another factor to keep in mind.

Modern communication technologies depend on taxpayers and are affected by the number of municipal governments within a county due to the number of cellular towers versus size, population and terrain.[4,6,15] To institute a national system and streamline current infrastructure means extremely high start-up costs due to small volume of currently fragmented public safety systems and a limited number of suppliers.[12,14,16] Moreover, implementation is a long-term commitment so costs will vary depending on changes to future needs and market influences.

Although adoption of a national PSCS is growing, it is far from being complete. Specifically, there is limited access for certain demographic groups, such as the poor, some racial and ethnic minorities, the elderly, individuals with disabilities and those who live in rural or geographically isolated areas.[17] The national system does project a fixed infrastructure reducing the amount of equipment needed by increasing effectiveness and enhancing the quality and utilization of service.[4,10] Spectral efficiency is a technical possibility for today's PSCS and mostly supports first responders; however, inefficient use increases the risk of shortages. Although the Federal Communications Commission (FCC) allows public safety agencies flexibility in distinguishing spectrum usage, responsibility and control is primarily in the hands of local agencies.[4,15] A benefit of local control is the ability to match resources (e.g. tax dollars) to pressing needs; yet, this comes at a cost as the local flexibility negatively impacts overall efficiency due to the independent selection and use of the wireless technologies. Thus, like in most other “distributed authority” systems, interoperability and cooperation among the local agencies towards a larger good becomes a challenge.

Wireless Broadband Spectrum Sharing Policy

With the thousands of independent systems in current operation, a proposition alongside the national PSCS is a nationwide wireless broadband network to potentially address all shortcomings.[18] Peha[4] reported the development of such a network under the supervision of the Department of Homeland Security (DHS).[29] Although the network was explicitly slated for law enforcement, it was predicted to support 80,000 federal agents and officers. In addition, this Integrated Wireless Network was supposed to be more cost-effective and spectrally efficient. As of 2012, the Department of Justice (DOJ) ended the program. When this program was discontinued, the US Congress signed into law the Middle Class Tax Relief and Job Creation Act. This act proposed the creation of a national First Responder Network (FirstNet) to generate and operate the first nationwide, high-speed wireless broadband network for public safety.[19] To fund this venture, responsibility was given to the FCC to conduct a two-sided auction for spectrum reallocation as well as continue development of main emergency communications components, such as: 1) the 911 call processing and delivery system; 2) the Emergency Alert System; and, 3) the radio/broadcast or television system.[22]

In addition, a National Broadband Plan (NBP) was developed to strategize a ten-year implementation plan for a public safety broadband infrastructure.[12] The NBP is a multi-faceted approach to wireless infrastructure through several avenues including: a) hardened Radio Access Network infrastructure to enable a higher degree of coverage, resilience, and signal reliability; b) priority roaming on commercial networks for additional capacity and increased network resilience; c) underground and in-building solutions for better coverage; and d) mobile technology for coverage during failures or remoteness.[12] The integration of these services influences the broadband ecosystem by: 1) maximizing consumer welfare, investment and innovation through policies designed for robust competition; 2) encouraging competitive entry and network upgrades through government influences or controls to ensure management and efficient allocation; 3) boosting adoption and utilization as well as ensuring affordability through reform relating to current deployment of universal service mechanisms; and 4) maximizing benefits for various sectors through policy, standards, incentives, and regulatory reforms.[17]

Spectrum Sharing Regulation

After discussing each indicator of an “ideal” system, a prominent challenge regards spectrum sharing policy and regulation to ensure wireless and mobile broadband networks thrive.[17] Within the current PSCS infrastructure, the US, along with governments around the world, are researching ways to make spectrum more available for mobile use and other services involving wireless broadband technologies.[8,20,21] One area of spectrum research is modification of sharing regulations and the impact on effective and efficient utilization of wireless systems.[16,20,23] Historically, experimental spectrum sharing began with researchers examining the relationship between top mobile providers and the Department of Defense along with the negative or positive impact on wireless services.[1,4] This initiative was called the Defense Advanced Research Projects Agency (DARPA) and focused on ways of increasing the capacity of wireless broadband services across the country.[21]

In addition, spectrum was divided by the government into non-overlapping blocks and then distributed via licenses. Currently, spectrum management is split between the FCC for nongovernmental applications and the National Telecommunications and Information Administration (NTIA) for governmental purposes. The President also maintains overarching authorization.[19,24] However, the market-based approach developed within the late 1950s as spectrum was deemed property most efficiently utilized when managed by private users. These users were believed to internalize the benefits and costs while appropriately selling valuable bands to other vendors.[24] Issues with this exclusive market-based approach soon surfaced regarding license allocation and costs. Auctions were then designed to create incentives for bidders and encourage robust competition while balancing concerns, such as spectrum geography, bandwidth, price setting, and format of the application. Critiques of this market auction consist of the timeline for implementation, associated costs, transparency of regulations, perception of spectrum and inclusion of stakeholders.[23,24,25]

Although exclusive access eliminated interference, the licensing process limits sharing capability and access. These barriers also prevent the ability to balance a streamlined, yet flexible wireless communication system for public safety (see Figures 1 and 2 for comparative purposes). Attempting to breach the barriers, Desourdis[19] proposed a balance between a standardized and flexible approach to allow vendor competition. Zhao and Swami[26] built upon this objective and generated three models for spectrum access ranging from a dynamic exclusive use model to an open sharing model referred to as spectrum commons and a hierarchical access model. However, difficulty surfaced due to tension between primary and secondary users regarding performance and protections.[26]

Figure 1.

Figure 2.

An Wang and Brown[27] gave an additional avenue through describing a two-stage pricing combination using a sound static policy for pricing setting a specific level of commercial traffic followed by an optimal dynamic policy for admission control. The benefits included efficient spectrum sharing without requiring additional availability, more stable revenue between commercial network and users, and an ability to adapt quickly if network conditions change.[27] According to a report by the President's Council of Advisors on Science and Technology (PCAST),[28] another recommendation was to implement a more constructive management system utilizing allocations and incentives connected to Spectrum Currency in a market system. The current management systems of spectrum sharing include the Spectrum Access System (SAS) and the Emergency Response Interoperability Center (ERIC). SAS is an avenue for spectrum allocation between commercial and federal entities while ERIC is a committee-based partnership to establish a common technical framework and process through issues of security and encryption, roaming, and priority access.[12] The newer system would utilize a three-tier interference protection: incumbent, secondary, and general authorized access.[28] Decisions regarding spectrum-sharing regulations affect a multitude of stakeholders and incorporate a plethora of long-term and short-term needs.[20,24,25] By acknowledging who is utilizing spectrum, their location and effectiveness with operation, policy makers are better able navigate implications and forecast effects of innovation and increased competition.[20]

Challenges for Spectrum Sharing Public Safety Communication

Although the national PSCS is capable of benefiting the nation as a whole, there are some critical challenges to address beginning with whether a centralized system is the solution versus a decentralized system. A centralized system would be more efficient in regards to integration and coordination of components along with increased interoperability[15] and is projected to outperform a decentralized system in terms of managing public safety communication networks. However, a decentralized system is more flexible and adaptable to local needs and preferences resulting higher social welfare.[2,4] Within a centralized approach, interoperability is promoted and projected to provide a higher quality of service; however, this system cannot completely address specific local needs and includes high costs to build a fully interoperable network.[9,14,15]

Another issue is how policy-makers manage and connect local-based systems while bridging into the commercial market to assist in production, innovation and competitive pricing.[4,6,10,12] The field of communication technology is constantly evolving and is a space for innovative advances. For instance, the Internet was first utilized in a public safety capacity through the military due to its capabilities of surviving destruction of critical communication points while intelligently routing traffic around busy spots.[2] Another example is the development of wireless technology in conjunction with the Internet allowing for needed flexibility, but also adding to the complexity of the communication infrastructure. This connects to concerns on covering all geographic areas, maximizing capacity and promoting strategic infrastructure allocation while minimizing spectrum needs.[4,13]

Several researchers highlighted policies specifically for spectrum allocations, reassignments and unlicensed usage in the context of sharing spectrum within a wireless network infrastructure along with impediments due to cost changes of access structures, spectrum-efficient technologies, and policies.[11] The lack of incentives for federal agencies to share spectrum or allocate usage temporarily can be another barrier.[24,25] In addition, stakeholders must be careful in maintaining public-private partnerships whose primary focus is not on profitable areas alone; otherwise, vulnerable populations will be at a disadvantage because of the unprofitable nature of building-out a network.[18] This cautionary note is due to integrating for-profit commercial providers in the operation of service and the impact of this relationship.[18]

Conclusion

In the wake of every disaster, coordination of wireless communication among public safety agencies encounters various disruptions and challenges due to fragmented systems and limited spectrum availability. Since the September 11, 2001 terrorist attacks, EM planning has focused on enhancing communication, coordination, and collaboration of wireless communication infrastructure and operational procedures.[11] This is dependent upon the creation of sensible policies defining partnerships, roles and responsibilities, governance structures, and requirements concerning decision makers.

Integrating plans, such as the NBP and the NECP, will be challenging and require a great deal of time. Once the strategic plans are in place, policymakers must also predict future needs, such as population and terrain changes, as gaining access to spectrum and connecting infrastructure will, at some point, compromise public safety.[1,12,16] Moreover, the reality of the situation must be understood in that all technology will need to be created and adapted for innovative spectrum coordination and cooperation between disparate networks.[14]

Open and transparent dialogue between and within the stakeholders is essential. For instance, PSCS agencies must express operational needs and the groups they represent just as much as commercial operators must understand the requirements before making a decision.[18] Regardless of the challenges, development and growth of PSCS is not a hopeless cause, as seen through the coordination of response agencies during the Boston Marathon Bombings. Yet, if a national public safety system is to become a reality, then stakeholders must understand spectrum sharing is not clearing and is not a pipe dream.

References

1. Faulhaber GR. Solving the interoperability problem: are we on the same channel: an essay of the problems and prospects for public safety radio. *Fed Comm LJ*. 2006; 59: 493.

2. Kapucu N. Interagency communication networks during emergencies boundary spanners in multiagency coordination. *Am Rev Public Adm*. 2006; 36(2): 207-225.

3. Manoj BS, & Baker AH. Communication challenges in emergency response. *Commun ACM*. 2007; 50(3): 51-53.

4. Peha JM. From TV to public safety: the need for fundamental reform in public safety spectrum and communications policy. http://repository.cmu.edu/cgi/viewcontent.cgi?article=1022&context=epp. Published October 2006. Accessed August 1, 2015.

5. Waugh WL. The political costs of failure in the Katrina and Rita disasters. *Ann Am Acad Polit SS*. 2006; 604(1): 10-25.

6. Hallahan R, & Peha JM. Quantifying the costs of a nationwide broadband public safety wireless network. In *36th Telecommun Policy Res Conf*. http://repository.cmu.edu/cgi/viewcontent.cgi?article=1039&context=epp. Published September 2008. Accessed August 3, 2015.

7. Ansari N, Zhang C, Rojas-Cessa R, Sakarindr P, & Hou ES. Networking for critical conditions. *IEEE Wirel Commun*. 2008; 15(2): 73-81.

8. Fantacci R, Vanneschi M, Bertolli C, Mencagli G, & Tarchi D. Next generation grids and wireless communication networks: towards a novel integrated approach. *Wirel Commun Mobl Comput*. 2008; 9(4): 445-467.

9. White House. Expanding America’s leadership in wireless innovation. *White House*, *Office of the Press Secretary*. http://assets.fiercemarkets.net/public/newsletter/fiercewireless/whitehousememo.pdf. Published June 14, 2013. Accessed August 1, 2015.

10. Habib I, & Mazzenga F. Wireless technologies advances for emergency and rural communications. *IEEE Wirel Commu*. 2008; 15(3): 6-7.

11. Hu Q, Knox CC, & Kapucu N. What have we learned since September 11, 2001? a network study of the Boston Marathon Bombings response. *Public Adm Rev*. 2014; 74(6): 698-712.

12. Manner JA, Newman S, & Peha JM. The FCC plan for a public safety broadband wireless network. In *38th Telecommun Policy Res Conf*. http://www.ece.cmu.edu/~peha/FCC_plan_for_public_safety.pdf. Published 2010. Accessed August 1, 2015.

13. Meissner A, Luckenbach T, Risse T, Kirste T, & Kirchner H. Design challenges for an integrated disaster management communication and information system. *IEEE Worksh Dis Recov Netwo.* 2002; (24).

14. Rysavy P. Spectrum sharing: the promise and the reality. *Wirel Spectrum Res Develop Worksh IV, MIT.* Cambridge, MA. http://www.rysavy.com/Articles/2012_07_Spectrum_Sharing.pdf. Published July 2012. Accessed August 1, 2015.

15. Liu Y, Guo H, & Nault BR. Centralized versus decentralized provision of public safety networks. *Technology*. 2014.

16. Werbach K, & Mehta A. The spectrum opportunity: sharing as the solution to the wireless crunch. *Int J Commun*. 2014; 8: 22.

17. Federal Communications Commission. National broadband plan. https://www.fcc.gov/national-broadband-plan. Published March 17, 2010. Accessed August 1, 2015.

18. Hallahan R, & Peha JM. The business case of a network that serves both public safety and commercial subscribers. *Telecommun Policy*. 2011; 35(3): 250-268.

19. Desourdis RI. *Emerging public safety wireless communication systems*. Artech House; 2002.

20. Doyle L, & Forde T. A regulatory perspective on cognitive radio and spectrum sharing. *Cogn Radio Net Hetero Wirel Networks.* 2015; 257-289. Springer International Publishing.

21. Power T., & Strickling L. Supporting innovative approaches to spectrum sharing. http://www.whitehouse.gov/blog/2013/03/11/supporting-innovative-approaches-spectrum-sharing. Published March 11, 2013. Accessed August 1, 2015.

22. Federal Communications Commission. Emergency communications guide. http://www.fcc.gov/public-safety. Published October 30, 2014. Accessed August 2, 2015.

23. Government Accountability Office. Spectrum management: incentives, opportunities and testing needed to enhance spectrum sharing (GAO 13-7). http://www.gao.gov/assets/660/650019.pdf. Published November 14, 2012. Accessed August 2, 2015.

24. Skorup B. Reclaiming federal spectrum: proposals and recommendations (Mercatus Center Working Paper 13-10, George Mason University). http://mercatus.org/publication/reclaiming-federal-spectrum-proposals-and-recommendations. Published December 27, 2012. Updated May 11, 2013. Accessed August 2, 2015.

25. Faulhaber GR. Commentary on “the spectrum opportunity: sharing as the solution to the wireless crunch”. *Int J Commun*. 2014; 8: 12.

26. Zhao Q, & Swami A. *A survey of dynamic spectrum access: Signal processing and networking perspectives*. California University: Department of Electrical and Computer Engineering; 2007.

27. Wang Q, & Brown TX. Public safety and commercial spectrum sharing via network pricing and admission control. *IEEE Lect Notes Commun.* 2007; 25(3): 622-632.

28. President’s Council of Advisors on Science and Technology. Report to the President: realizing the full potential of government-held spectrum to spur economic growth. http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf. Published July 20, 2014. Accessed August 3, 2015.

29. Department of Homeland Security. National emergency communications plan. http://www.dhs.gov/sites/default/files/publications/2014%20National%20Emergency%20Communications%20Plan_October%2029%202014.pdf. Published September 8, 2014. Accessed August 3, 2015.