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Lessons learned from deployments and trials of Public Safety Broadband Networks

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Abstract

This Reference Document provides a summary of various trials and deployments of Public Safety Broadband Networks (PSBNs), both in Canada and internationally, as well as a survey of lessons learned from these. The content is organized around three broad categories, Canadian trials, U.S. trials, and international trials.

This document provides a general overview of available feedback and guidance based on trials and deployments of PSBNs. The document is intended to serve as supporting material for policy decision-making in relation to the creation of a Canadian PSBN.

Résumé

Le présent document de référence contient un résumé des divers essais et déploiements de réseaux à large bande de sécurité publique (RLBSP), au Canada et à l'étranger, en plus d'une étude sur les enseignements qu'on en a tirés. Le contenu est réparti en trois grandes catégories : les essais canadiens, américains et internationaux.

Le présent document donne un aperçu général de la rétroaction et de l'orientation offertes en fonction des essais et des déploiements des RLBSP. Il est destiné à servir de document d'appui à une politique concernant la prise de décisions stratégiques relatives à la création d'un RLBSP canadien.

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1 Background

In North America, Public Safety Broadband Networks (PSBN) for communication purposes by public safety workers have been in development since 2012, when the Governments of Canada and the United States set aside a portion of the 700 MHz spectrum for the public safety community. A PSBN is, broadly, a wireless network that operates on a distinctive band of electro-magnetic frequency either set aside, or ensured to be available and prioritized, for the public safety sector. A PSBN would provide public safety workers from different agencies and jurisdictions with an interoperable communication medium, thereby improving coordination. PSBNs are intended to leverage Long Term Evolution (LTE) technology to realize networks that are reliable and secure for public safety workers, enabling the use of diverse information sharing, video-streaming, photo uploading, situational awareness, mapping, and real-time database updating applications that can enhance operations. One particular technical challenge is ensuring that mission-critical voice communication is as robust across LTE as it is in current voice radio systems such as Land Mobile Radio (LMR) in North America and Terrestrial Trunked Radio (TETRA) in Europe and other locations. Another challenge is to ensure public safety workers will always be able to access critical information and communicate with each other during crises, when commercial LTE networks are likely to become crowded by many individuals attempting to use them.

Various deployment options exist for PSBNs and are being implemented in different countries, including a) the *dedicated model* of setting aside a distinctive Radio Frequency (RF) band for the public safety sector of a country that would be managed on their behalf by one or more commercial carriers but is not available to commercial uses; b) the *commercial model* in which the public safety sector of a country as a whole, or alternatively individual public safety agencies, contract with one or more mobile carriers to obtain priority access to the RF spectrum to which the carrier has rights, and which may or may not involve the specific designation of a RF band for this purpose[1]; and c) the *hybrid model*, whereby one or more mobile carriers are contracted to manage the public safety sector's dedicated spectrum, often with the right to use that portion in agreed-upon ways when it is being underused by the public safety sector [1]. In some hybrid deployments, carriers are additionally expected to supplement the dedicated public safety spectrum with additional spectrum as required, for instance in times of extreme emergencies.

[1] In Fournier & Lucente (2017) [1] the commercial model is described as one in which "20 MHz of spectrum [is] awarded by auction to a commercial mobile network operator to be used with certain conditions for prioritized public safety users" (2–3). However, as in the international context numerous other bands of dedicated and non-dedicated spectrum are used in commercial models of PSBN, the definition of the commercial model has been broadened in this document.

2 Methodology

Four categories of PSBN deployments and trials are surveyed in this document: Canadian, Canada-U.S., U.S., and International. International deployments and trials were grouped into four regions: Asian Pacific, Europe, South America, and Middle East.

Some of the documents used were provided by Defence Research and Development Canada's Centre for Security Science (DRDC CSS) subject matter experts who were involved in their publication, while others were obtained from outside experts with whom DRDC CSS SMEs had collaborative relationships. An additional scan of Internet search results using search terms such as Public Safety Broadband Network Trials, Public Safety Wireless, and Public Safety LTE produced additional relevant documents. Official after-action reports, informal reports such as PowerPoint presentations, as well as "grey literature" (media articles) were all consulted. All the documents thus identified were examined with a view to bring together overall trends in the lessons learned to draw conclusions relevant to Canada. It should be noted that this Reference Document does not itself attempt to assess decisions made by other countries with respect to their PSBN implementations, beyond aggregating assessments that could be found in public documents and literature.

There were limits to discovering information on lessons learned from PSBN trials and deployments in the public sphere. For one thing, neither public safety agencies nor corporate entities developing solutions for them are research entities, and neither typically report on activities in a systematic way. Public safety agencies are likely to have concerns about revealing operational details to the public, while commercial companies are likely to resist releasing proprietary details about their technology or indications of problems revealed in tests. Accordingly, some documents provided little information about operational details and lessons learned. Another limitation was that the trials and deployments reviewed were conducted at different times, and so the lessons and conclusions they reported might have been contingent on technological conditions as they were either existing or forecasted at the time, which may have changed, or may change in the future.

With those caveats in mind, 105 lessons learned from 10 countries were discovered and incorporated into this document. Information on the United States (U.S.), Canadian, United Kingdom (UK), and Australian situations were especially plentiful: the former two presumably because of requirements on public safety agencies to make research and development information public, and the latter two because their deployments have been subject to open parliamentary inquiries and commissions.

3 Aim

The purpose of this Reference Document is to assemble, for Canadian policy guidance, lessons learned in trials and deployments of PSBNs in Canada, the U.S., and internationally. The document is broken up into three sections, 1) Canadian trials and deployments; 2) U.S. trials and deployments; and 3) International trials and deployments. In each section, an overview of each pertinent trial and deployment of a PSBN is described, parameters of the deployment and/or trial are summarized, and lessons learned from the deployment and/or trial are listed. Ultimately, these lessons are synthesized in the Analysis and Conclusion sections into general advice for the implementation of a Canadian PSBN.

4 Results

4.1 Canadian PSBN trials

4.1.1 Calgary Police Service (2014) [2]

Overview: In 2014, Motorola designed and implemented a one-year Public Safety Broadband network trial in 2014 for Calgary Police Service, the first such trial for a police service in Canada, in order to allow client-based operational capability testing. Calgary Police Service hosted the required equipment for the trial PSBN. Additional devices integrated were "virtual beat cop" cameras providing remote monitoring of high crime areas, surveillance systems to support covert operations, and intersection cameras.

Parameters: Motorola supplied and operated a LTE Evolved Packet Core, Seven Evolved Universal Terrestrial Radio Access Network (EUTRAN) sites, and 100 subscriber devices consisting of rugged trunk-mounted vehicular modems with local Wireless Networking (WiFi) Access Points and routers, mounted antennas, and internal GPS support. Calgary Police Service provided facilities to support the radio sites and the network core, including physical space, power, and data backhaul facilities.

Lessons learned (implementation stage):

1. Labour and space requirements for PSBNs' hosts are intensive, including the need for coordinating access with and escorting providers and for receiving delivery and storing of required equipment;

2. Power infrastructure may need to be augmented for sites hosting PSBN equipment;

3. Site designs for the antenna equipment should strive to mount equipment at heights that would be acceptable per local guidelines (municipal rules, etc.), otherwise, obtaining permits for higher antenna structures can be laborious and introduce deployment delays;

4. Network data backhaul via fiber optic cable is valuable, eliminating the need for support from 3rd party Internet carriers and providing ample bandwidth to the Radio Access Network (RAN);

5. If and until the PSBN becomes the sole communications tool, additional new modems and antenna mounts on vehicles must compete for space;

6. Allowing a range of business units to utilize the PSBN was regarded to be valuable in order to amortize its costs more quickly.

4.1.2 British Columbia (B.C.) interior (2015) [3]

Overview: A Canadian Safety and Security Program (CSSP) project undertaken by Simon Fraser University's Telematics Research Lab was funded to investigate how to introduce PSBN capabilities by developing deployable communications systems in locations where conventional communications infrastructure is non-existent. This pilot, located in Ashcroft, B.C., was a preliminary scoping exploration of how to introduce a deployable PSBN capability via specially-equipped vehicles, building up to a larger pilot to be undertaken in Yukon in 2017–2018.

Parameters: The project scoped and tested the forms of backhaul, satellite links, radio frequency links, optical laser links, compact evolved packet cores, and power required to support remote PSBN functionality; as well as the requirements for providing adequate coverage, capacity, authentication, access control, routing and switching, voice and land mobile radio integration and prioritization for first responders. Specific applications tested included the *Truvian* data mapping application (now embedded in the *Lightship* data management platform) to input and map information such as damage reports, structure assessments, injury reports, and evacuations.

Lessons learned:

1. Requirements for relatively continuous PSBN communications in remote areas can be accurately projected and adequately supplied;

2. Consumer internet services may be inadequate for providing system backhaul for Public Safety LTE to remote areas, as standard modems and routers may be unable to handle the additional traffic that can be introduced by first responders using LTE applications—especially picture-sharing and video-applications;

3. Satellite connections and virtual private networks connected to dedicated servers may be suitable alternatives; however, satellite connections may not suffice for applications requiring extremely high performance;

4. User equipment such as hand-held devices should be capable of being debugged, including diagnostic and reconfiguration capability, to avoid crashes and overcome problems introduced by new system demands;

5. Applications such as mapping interfaces should provide the sender with an indication that information has been delivered, the absence of which could signal transmission failures due to spotty communication coverage.

4.2 Canada-US trials

4.2.1 CAUSE III (2015) [4]

Overview: DRDC CSS, Public Safety Canada, and the Department of Homeland Security Science and Technology First Responder Group collaborated in the development and conduct of the Canada–United States Enhanced Resiliency Experiment series, CAUSE. In the third experiment, CAUSE III, the Western scenario compared two responses to a rangeland brush fire. The first response deployed interoperable cross-border land mobile radio (LMR) systems to a remote area where no communications previously existed. The second response complemented the LMR with a high-speed 700 MHz broadband LTE capability through wireless backhaul, thereby leveraging the World Wide Web to allow all emergency responders and managers in Saskatchewan, Alberta and Montana to communicate using feature-rich broadband applications.

Parameters: The LTE networks in Canada were designed, configured and installed by DRDC CSS and Communications Research Centre (CRC), with Motorola additionally installing and operating a deployable LTE system in Wild Horse, Alberta. The US LTE network installation and operation in Montana was led and coordinated by Texas A&M. A cellular data link, required to provide data backhaul from the LTE network to the Internet for inter-jurisdictional interoperability purposes and application support, was enabled by an aerostat, a 17 meter long helium-filled tethered balloon approximately 200 meters above ground. Connectivity to the Internet permitted access to the Multi-Agency Situational Awareness System (MASAS), voice and video conferencing, email, photo and video clip exchange, Voice over Internet Protocol (VoIP), and a high definition video feed from the aerostat.

Lessons learned:

1. Information exchange and situational awareness are enhanced when voice transmissions via LMR are augmented by the transmission of data via broadband LTE capabilities. LTE-enabled tools and applications allow incident-critical data to be shared among users in real time via VoIP, emails with and without attached images, audio/video conferencing, live streamed video, and through the MASAS mapping application that generated a real-time common operating picture that all participants could view using mobile technology applications;

2. LTE systems are more complex to implement and more laborious to use than current radio technologies, requiring strategies for mitigating technology risks. These include:
   - engaging the emergency responder community to identify requirements for tools and applications;
   - engaging the vendor community to troubleshoot and solve integration issues;
   - modifying existing standard operating procedures for first responders to accommodate the effective sending and receiving of data;
   - providing training and collaboration opportunities to managers as well as operators to gain familiarity with incoming technology features and functionalities including deployable LTE networks, wireless applications, and real-time information sharing platforms such as MASAS.

3. Pre-established mutual aid agreements and bi-national concepts of operations for deployable LTE systems are required to strengthen interoperable communications and coordination in emergencies. Concepts of operations should be based on US and Canadian agencies' joint determinations of interoperability requirements affecting near-border and cross-border operations of their respective LTE systems. An engaged first responder working group and bi-national outreach and training campaign would be desirable to improve the sharing of information over broadband wireless networks on both sides of the border.

4.2.2 CAUSE IV (2016) [5]

Overview: Interoperable cross-border emergency communications capabilities were also tested during the fourth experiment in the CAUSE series, CAUSE IV, held on April 26–28, 2016, at the border crossing between Sarnia, Ontario, and Port Huron, Michigan. Vignette 1A of this experiment established and tested a cross-border 700 MHz PSBN while implementing a variety of voice, video and data communications and information sharing applications. These applications included resource planners, Linphone (voice), Google Hangouts (video), Gmail, Siren-Geotrigger Alert Systems, Automatic Vehicle Location, and an application (iMedic Generation II) for the updating and transmittal of patient care records and 12-lead strips while paramedics were en route. Vignette 1B additionally established a real-time video conference supporting continuous cross-border communications and information sharing between physicians and paramedics. Vignette 2 tested and compared a suite of mapping and notification tools during a large tornado event to share alerts, warnings, and notifications both locally and cross-border between digital volunteers and emergency managers on both sides of the border. Many of the applications tested in the vignettes were openly available, though PSBN enabled their application in the context of first response.

Lessons learned:

1. Existing LTE data-sharing, data-visualization, voice communication, and video-sharing applications could be imported or customized into response operations to improve communication flow, need and risk identification, information exchange, information integrity, alerting, permissions access, situational awareness and decision-making among first responders;

2. Many currently used communications protocols for public safety agencies to produce situational awareness could readily be transitioned from existing technologies (radio, fax, phone) to emerging LTE voice, video and data applications;

3. Multi-party call communication formats in LTE should be networked through existing dispatch systems to ensure dispatchers are aware of all communicated content and have a common operating picture;

4. LTE-enabled information sharing applications should incorporate prompts to acknowledge or confirm the receipt of non-verbal (data) information and provide follow-up information;

5. Some new LTE-enabled applications might be initially demanding for first responders to use and may impact response capabilities if adequate training and exercising is not provided. Implementing several new applications at once could also lead to a requirement for considerable technical support to configure and maintain the technology;

6. Modifications to applications are required such as better layering of response data from different applications, tools to assign priority levels (e.g., via colour codes), and request archiving are required to reduce first responders' need to monitor multiple applications simultaneously and to help them prioritize needs;

7. PSBN has special value in cross-border patient transfers by minimizing risks and enhancing patient care. Currently, radio and ministry-issued phones do not function across borders and hence, are unable to effectively communicate updates;

8. Currently there are few procedures, policies and agreements enabling cross-border information sharing, and the use of common platforms for sharing information (e.g., ArcGIS Online) is infrequent. The development of cross-border interoperable communications must be accompanied by bi-national agreements such as Memoranda of Understanding to enable cross-border operational elements;

9. Significant bandwidth as well as scope within the system to increase capacity and data allowances will be required in PBSN networks to prevent lags or crashes of the system with multiple applications running simultaneously in real-world events, especially when sharing video;

10. Local servers are potential single points of failure when monitoring, visualizing and sharing large volumes of information via PSBNs, likely requiring agencies to subscribe to cloud server technologies;

11. Privacy concerns related to the exchange of records through PSBN need to be addressed prior to implementation.

4.3 U.S. trials [6] [7] [8] [9]

Overview: In the U.S., First Responder Network Authority (FirstNet) was created in 2012 as an independent authority within the National Telecommunications and Information Administration with the mandate to establish, operate, and maintain an interoperable PSBN. The construction of the nationwide FirstNet network requires each state to have a RAN that will connect to FirstNet's network core.

Since 2013, FirstNet has been consulting with states, local communities, and tribal governments to develop the requirements for its RAN deployment plan. Each state was given the option to either allow FirstNet to create the RAN or to "opt out" and create its own RAN with an alternative provider, which had to nonetheless use the FirstNet network core and meet FirstNet requirements. As of the December 2017 deadline, all states & territories had opted-in to FirstNet [10].

In 2017, FirstNet officially chose AT&T to build and manage its U.S. PSBNs. AT&T plans to create a nationwide seamless, IP-based, high-speed mobile communications network that will give first responders priority access and that will evolve to keep the public safety community at the forefront of technology advances. In particular, FirstNet will provide 20 MHz of high-value, telecommunications spectrum and success-based payments of $6.5 billion over the next five years to support the network buildout; AT&T will spend about $40 billion over the life of the contract to build, deploy, operate and maintain the network; and AT&T will connect FirstNet users to the company's commercial telecommunications network assets, valued at more than $180 billion.

Two other American carriers initially indicated an intention to compete with AT&T to construct state-wide RANs for states that opted out of FirstNet [11]. Verizon announced its intention to build a dedicated network for public safety that will operate separately from Verizon's commercial core but enable emergency workers to access the company's LTE network. Verizon did not intend to use Band 14 (the North America specific spectrum for public safety) for its competing solution, but rather alternative network configurations interoperable with the FirstNet core, such as core-to-core interconnection and mutual automatic roaming arrangements. Rivada Networks also proposed to build and maintain statewide public safety radio access networks that represented alternatives to the FirstNet/AT&T option while still using Band 14, and initially announced a partnership with U.S. Cellular to meet New Hampshire's PSBN coverage requirements. However, New Hampshire reversed its earlier "opt-out" decision and ultimately chose to "opt-in" to the FirstNet solution.

While Rivada has since apparently bowed out of Public Safety broadband in the U.S., Verizon claims to still be committed to building an alternative dedicated public safety network core. Although all 50 states have committed that FirstNet will be their PSBN supplier, individual first responder agencies are not obliged to use the FirstNet network, and so Verizon will likely attempt to sell its alternative services to these agencies. Verizon has said it would make priority access and pre-emption services on its commercial network available to public safety as necessary and at no charge to complement existing services such as its Push-to-Talk Plus, which is interoperable with existing land mobile radio networks.

FirstNet has been testing and deploying PSBNs in various regions of the U.S. since 2014; details of specific municipal and state trials and deployments of PSBNs follow in Sections 4.3.1 to 4.3.7.

Lessons learned:

1. AT&T anticipates that the network they are building will improve rescue and recovery; better connect first responders to the critical information they need in an emergency; further the development of public safety focused Internet of Things (IoT) and Smart City solutions; and enable advanced capabilities, like wearable sensors and cameras for police and firefighters, and camera-equipped drones and robots [12].

2. State representatives expressed concern in Senate Hearings on FirstNet that rural coverage requirements will not be met by FirstNet and the ~$7 billion budget for the program will not be enough funding to provide the necessary build-out of the network [13].

3. Competing carriers, as well as former elected officials, complained of a lack of transparency in the FirstNet/AT&T opt-in proposal being offered to states, on the grounds that states were not given full explanation of the value and costs of what they are opting into [9]; that the value proposition of the A&T/FirstNet proposal is ill-defined; and that it is not in the best interests of all states. States also expressed that FirstNet did not fully demonstrate that their proposed coverage provided added value over existing commercial options in terms of user cost and coverage reliability. It was contended that to meet the needs of States, it would have been better to construct the relationship of FirstNet with States as a partnership rather than a "grantee-grantor relationship." [13]

4.3.1 East Bay, California [14]

Overview: In 2011, Andrew Seybold, Inc. was contracted by the East Bay Regional Communications System Authority to undertake a series of network capacity tests for the first 700 MHz system in the United States to deploy LTE. The network operated in 10 MHz of spectrum licensed to the Public Safety Spectrum Trust in anticipation of the integration of the East Bay Regional Communications System Authority with the planned nationwide, fully interoperable, broadband network dedicated to public safety.

Lessons learned:

1. 10 MHz of spectrum was insufficient to meet incident requirements such as the sending of videos, which tended to freeze and break up due to inadequate capacity for the uploading, downloading, and streaming of videos. The overloading of the network due to data requirements in a video blocked the introduction of new video and data streams and caused ongoing video and data streams to become unusable. The addition of voice applications, which were not tested in this experiment, would have even further stressed bandwidth requirement;

2. 20 MHz is likely sufficient for most public safety applications, with contiguous spectrum ideal since non-adjacent spectrum will significantly increase the cost of the network and of the devices used;

3. At edge-of-cell coverage situations, even 20 MHz may be stretched, thus edge-of-cell situations should be reduced through the use of overlapping cell coverage, with interference between overlapping cells minimized;

4.3.2 FirstNet Early Builder projects (2014–2016) [15] [16] [17]

Overview: Between 2014 and 2016, FirstNet granted five "Early Builder projects" access to deploy LTE networks on its licensed 20 MHz "Band 14" spectrum in the 700 MHz band, in order to explore different aspects of first responder use of the public safety network. The five agencies involved as Early Builders were 1) Adams County Communications Center (Adcom911); 2) Los Angeles Regional Interoperable Communications System (LA-RICS); 3) Harris County, Texas; 4) New Jersey's JerseyNet; and 5) New Mexico Public Safety LTE Network.

Parameters: Focusing on different aspects of first responder use, the projects have helped FirstNet evaluate technical standards and capabilities, test new equipment, and refine plans for future rollouts.

Lessons learned: FirstNet has elicited 191 lessons learned from across these experiments, though not all are publicly available. Some of the more general publicly available lessons are as follows:

1. In comparison with prior commercial support, the value of a dedicated PSBN to first responder agencies for major public events was extensively demonstrated, both in terms of ensuring reliable and fast network access and access to applications not generally available to public safety;

2. Due to restrictions on commercial access and use in public-private partnerships, reliance on public assets for site locations and network connectivity can pose a risk to deployment timelines and have negative operational impacts;

3. When using public assets, it is important to define and establish service level agreements that will drive high network reliability;

4. Staffing levels and qualifications for managing networks must be recalibrated, as the level of complexity in the management of an LTE network exceeds that of an LMR network. Knowledge must be shared so that departing employees do not become single points of failures;

5. Enhanced performance data on the health of the network and the user experience, beyond mere network status warnings, should be made available to project overseers;

6. Careful coordination of network upgrades or modifications are required to minimize strain on agencies and impacts on network users;

7. Although the main focus is on a dedicated network with its own spectrum, the FirstNet architecture is also supporting LTE access via partner mobile operators, according to the so-called hybrid model, which typically incorporates dedicated spectrum in urban areas while in rural areas the cost of coverage is reduced by sharing spectrum access with mobile operators. Allowing a mobile operator host to use the dedicated public safety spectrum for commercial services when it would otherwise be idle further ensures that dedicated spectrum allocations are not wasteful, and assists providers in overcoming the business model challenges that have hindered earlier attempts to bring a Public Safety Long Term Evolution (PS-LTE) network to the US market [18];

8. As Band 14 is the North America specific spectrum for public safety, it cannot use products from existing commercial LTE ecosystem; however the market is seen as large enough to attract device and network infrastructure vendors to develop products for band 14 [19].

4.3.3 Adams County, Colorado (ADCOM911) (2014–2016) [17]

Overview: A Band 14 LTE network covers Adams County, Colorado. Its capabilities have been tested in two trials, including one at the 2015 International Ski Federation's Alpine World Ski Championship in Vail on the use of video surveillance, situational awareness and photo applications, and another with Colorado Parks and Wildlife, which set up hunter safety checkpoints in rural areas with little to no connectivity.

Parameters: ADCOM911 has 19 LTE sites, more than 76 devices in active daily use, and a broadband test center for on-site device testing. At the Ski Championship trial, participants could use a push-to-talk (PTT) LTE application, could view enhanced video surveillance from five cameras, upload photos, and could conduct situational awareness and mapping. In the hunter safety checkpoint test, participants used wireless, ruggedized handheld devices to scan radio frequency identification (RFI) tags, query and enter information into databases in real time.

Lessons learned:

1. PSBN allowed operators to use PTT applications on LTE, view enhanced video surveillance; use situational awareness, photo uploading, mapping, and RFI scanning, querying, and uploading applications;

2. Tailoring PSBN networks and applications to meet operational requirements and ruggedizing and configuring devices for public safety use is time consuming. In this regard, a mobile device manager solution to streamline configuration of devices would be desirable;

3. Dedicated technical personnel are required to manage the daily operations of the LTE network and drive continual improvement;

4. Scheduled network maintenance times for public safety can differ from commercial standards due to differences in peak usage and user needs, sometimes entailing maintenance windows during daytime hours, which may mean modifying standard operating procedures for network operators.

4.3.4 LA-RICS (2014–2016) [15] [17]

Overview: The LA-RICS project team has 63 LTE sites and 14 Cell-on-Wheels sites. Fixed video cameras and mobile video units (both in-vehicle and body worn) have been tested at numerous events, and throughput monitoring and network settings have been closely analyzed. During the Rose Parade in Pasadena, California in January 2016, the project team successfully tested and demonstrated usage of the PSBN in support of law enforcement and fire service first responders assigned to the event.

Parameters: At the Rose Parade, 90 handheld devices, eight fixed cameras, six mobile cameras, and video and situational awareness applications were deployed.

Lessons learned:

1. It was observed that at the height of a major event, use of a dedicated LTE service can potentially be two-to-three times faster than relying on a commercial network, depending on specific congestion conditions;

2. Video streaming capabilities of the LTE network can enhance operations in complex events, for instance allowing dispatchers to guide personnel through the crowd to a problem location using live video from cameras along the route;

3. Before major events, it is important to set proper network configurations and to enable access to appropriate parties to the network tools so they can adjust network configurations if necessary;

4. More extensive standardization and certification of devices and applications is needed, as applications such as PTT do not typically operate on different devices or networks or recognize devices operating on other applications, creating interoperability risks;

5. Installation templates for routers and antennas are needed to reduce the challenge of installing devices on large fleets, where equipment and installation needs vary according to vehicle types and their electronic configurations;

6. Quality of Service Priority and Pre-emption techniques are currently low in functionality and need to be improved and tested.

4.3.5 Harris County, Texas (2014–2016) [17]

Overview: An LTE PSBN has been used to support several public safety communications initiatives, including the Houston Rodeo and Livestock Show and National Football League (NFL) football games at Houston's NRG Stadium.

Parameters: Harris County's LTE PSBN includes more than 100 user devices, averaging 60 devices in active daily use. At the Houston Rodeo, 120 handheld devices were deployed, equipped with PTT as well as situational awareness and information sharing applications. Wi-Fi hot spots were additionally deployed with Apple iPads and laptops running a tracking system to share person-of-interest bulletins, pictures of missing children, images of counterfeit parking passes, and other information.

Lessons learned:

1. The use of PTT over LTE by teams communicating non-emergency information can significantly reduce voice traffic on the main LMR security channel;

2. However, PTT over LTE devices may not yet support mission-critical voice communication, especially since PTT applications on LTE are not yet standardized and so their use presents an interoperability risk (this is being addressed by standards bodies such as the 3GPP);

3. Instead of carrying separate radio and data devices, operators would prefer integrated hands-free devices supporting LMR communications and smartphone functions; however those were not yet available;

4. Sources of interference were detected at major events that could potentially impact Band 14 LTE operations; these need to be monitored in an ongoing way.

4.3.6 New Jersey's JerseyNet (2014–2016) [17]

Overview: Police departments and the state Office of Homeland Security and Preparedness created a dedicated broadband network to supplement communications at a range of exercises and events, including Urban Search and Rescue and airport emergency exercises and tournaments and concerts where commercial systems were likely to be overloaded. The project focused on operational readiness preparation, enabling end-to-end network monitoring, and completing key operational and user training initiatives.

Parameters: The JerseyNet project team used five unique configurations of deployable assets to support in-state public safety communications initiatives involving more than 400 active users. Interoperable communications technologies were deployed, along with cells-on-wheels (COW) and systems-on-wheels (SOW) equipped with microwave backhaul, and trailer-mounted surveillance cameras. Information was shared to field resources, officers at the command center, and other service providers via workstations and mobile devices using interoperable communications technology bridging Band 14 and commercial networks.

Lessons learned:

1. PSBN permits constant real-time video streams to be maintained during large, densely populated events, vastly improving situational awareness for event security;

2. Unlicensed microwave radio service can expedite deployment but increases operational risk if it is deployed without a redundant solution.

4.3.7 New Mexico Public Safety LTE network (2015) [17]

Overview: The New Mexico project team is utilizing a remote LTE core located at the ADCOM911 Early Builder site and has completed construction of a PSBN including a RAN and sites adjacent to the Mexican border. The PSBN has supported in-state public safety communications initiatives including public events and an exercise with Department of Homeland Security Customs and Border Protection.

Parameters: The New Mexico project team utilizes a remote LTE host core located at the ADCOM911 site in Adams County, CO. It includes six fixed cell sites and a Cell-on-Wheels site. At the 2015 Albuquerque International Balloon Fiesta, an exercise was performed in which the Cell-on-Wheels site let law enforcement officials see in real time where public safety officers were located on a map of the festival field. End users carried ruggedized smartphones preloaded with PTT and situational awareness applications.

Lessons learned:

1. An Early Building Network in New Mexico facilitated the creation of user-friendly applications and devices with which operators were able to quickly gain competence and personalize;

2. Both handsets and vehicular modems may be required for events with large numbers of users operating on foot or away from vehicles;

3. Using smartphones while driving during vehicle operations can be unwieldy and dangerous, demonstrating the need for situational awareness applications to incorporate features that ensure driver safety, such as mapping technology for live tracking;

4. Cross-border interference challenges require identification and addressing.

4.4 International PSBN tests and deployments

4.4.1 Asian Pacific region

4.4.1.1 Australia (2012–2017) [20] [21] [22] [23]

Overview: In 2012, The Australia Communications and Media Authority was one of the first regulatory authorities in the world to assign dedicated spectrum to public safety in the 800 MHz range, designating 2x5 MHz slots in the 800 MHz spectrum band along with 50 MHz of spectrum in the 4.9 GHz spectrum band for the deployment of temporary cells on wheels. However, public safety agencies had wanted double this: 2x10 MHz spectrum in either the 700 MHz or 800 MHz band. In a Productivity Commission inquiry, it was recommended that the Public Safety Agencies and state governments be given the leftover 2x15 MHz spectrum from the 700 MHz band following the completion of the digital dividend auction in May 2013. This would circumvent the cost of building out a new network, as well as harmonise Australia's emergency services network with those from other countries that make use of the 700 MHz band, such as the United States, Canada, and South Korea.

However, in 2015, the Australian Government Productivity Commission's report opposed the dedication of existing spectrum for public safety on the grounds that it would be used more efficiently if auctioned. It instead observed that using existing networks of commercial providers for public safety would save $4 billion off of the cost of building an exclusive national mobile communications network for public safety agencies on the set-aside spectrum (predicted cost: ~USD $6.2 billion). A commercial solution would see public safety agencies continue to sign individual contracts for mobile network services and capacity with telecommunications providers, as they were currently doing.

Australia's largest mobile operator, Telstra, has since been conducting trials for public safety users using dynamic prioritisation and public safety-optimised devices over its LTE network with a service called LTE Advanced Network for Emergency Services (LANES). LANES will enable prioritised access not only for public safety mission critical services but also enterprise (business) mission-critical service [18].

Parameters: Telstra intends to combine its own spectrum with the dedicated spectrum awarded to public safety to offer additional resources in times of emergency. Telstra said it will initially provide access to up to 160 MHz in the 700 MHz LTE spectrum band. LANES dedicates specific "lanes" of spectrum for allocated purposes, with emergency services to have guaranteed priority access to a specific part of the mobile network. LANES was intended to open for law-enforcement and emergency services to use during summer 2016–17.

In 2016, Telstra released two LANES solutions: Telstra LANES Emergency Priority, an out-of-the-box solution that includes a LANES subscriber identity module (SIM) card for use in smart devices that provides access to a 24/7 national help desk and an online portal; and Telstra LANES Emergency Tailored, which will involve customer-owned dedicated spectrum augmented or enhanced by access to Telstra's 4G spectrum.

In 2016, Telstra tested LANES capability, including access prioritization, at a football game, with Ambulance Victoria utilizing an exclusive portion of Telstra's spectrum and also obtaining priority access to the network for burst capability.

Subsequently in 2017, Ericsson, Motorola Solutions, Telstra, and Qualcomm Technologies Inc. achieved the first LTE Broadcast enabled PTT call on Telstra's commercial LANES Solution. The enabling technology is based on the 3G Partnership Project (3GPP) Release 13, is complementary to existing LMR services, and can cost-effectively extend assured PTT service to a greater number of users via mobile devices. This technology can allow public safety agencies to extend PTT capabilities to more users, via both hardened devices and regular smartphones. Thereby providing coverage and capacity that is complementary to LMR networks—or even sufficient to replace them, if enough LTE cell sites are added

Lessons learned:

1. The Government of Australia's argument on behalf of commercial-driven Public Safety Networks was that there would be substantial cost savings, due to the public safety agencies being able to leverage and share existing infrastructure;

2. As well, they argued that a dedicated network ran the risk of taking longer to build out and deploy, and would provide less flexibility and scalability for the short term;

3. Leveraging the already existing commercial networks also meant public safety agencies will have 99 percent coverage of the Australian population immediately for 3G and 4G mobile broadband services;

4. Also according to Telstra, their tests of LANES have shown that that stadiums filled to capacity are no longer an issue for emergency services communication via the mobile network [24];

5. As well, PTT over LTE can extend the reach of existing LMR networks to many more technology users, regardless of whether they communicate with a smartphone, hardened device or a desktop computer;

6. Finally, Telstra holds that enterprise mission critical services, such as for the mining sector, additionally improved the business case for public safety;

7. In the short term, however, Telstra has no emergency agency customers. This perhaps suggests that the costs Telstra is charging are too high for agencies, and/or alternatively, that agencies remain concerned about the commercial driven model that was essentially adopted against their will. The Police Federation of Australia continues to hold that relying on commercial operators will not address coverage blackspots that threaten first responders' ability to communicate in remote areas because it is commercially unviable to extend network capacity into these regions;

8. A challenge for the commercial model anticipated by Australian Government Productivity Commission was that public safety agencies will be forced to share network capacity when territories overlap. To solve this problem, territory-straddling implementation entities are recommended to be formed in order to minimise duplication and improve economies of scale;

9. Additionally, the Productivity Commission cautioned that achieving interoperability as well as harmonies between public safety agencies using commercial systems will require jurisdictions to agree on common protocols covering matters such as network technology, spectrum, end-user devices, and applications, protocols for sharing information and, where PSMB capabilities are shared, network capacity.

4.4.1.2 China (2013-–2015) [25]

Overview: In 2013, China began building a national PS-LTE network covering more than 10 cities, including Beijing, Shanghai, Nanjing, Shenzhen, and Guangzhou. 256 base stations and over 10,000 end-user terminals are in service in Nanjing alone. Huawei has deployed a number of pre-standard professional LTE networks in 1.4 GHz in China for use by public safety in large events, allowing authorities to have access to services that cannot be provided by narrowband technologies such as TETRA. Particularly strong growth regions following the "safe cities concept" are tending to look more towards mobile broadband rather than traditional narrowband technologies.

Parameters: Huawei has signaled its intention to work closely with critical communications equipment suppliers to ensure the integration of the two systems. In 2013 it developed an LTE-based dedicated broadband network for the Nanjing municipal government, which built upon the latter's existing TETRA system. The expanded set-up enabled various operational functions including voice services, visualized command and dispatch, real-time municipal data monitoring (for information such as electricity and water consumption), video surveillance of transportation and key locations, and mobile offices.

Lessons learned:

1. As running TETRA and LTE systems simultaneously is seen as the way to provide double safety, security, stability and reliability, there are no immediate plans by Chinese authorities to switch off existing TETRA networks. Other factors leading to the decision to support two systems in parallel are issues surrounding the encryption of terminals and concerns about coverage in the mountainous and rural areas of mid- and western China;

2. A particular problem with migration to LTE in public safety in China is that LTE networks are operated by individual providers and are typically not interoperable. However, due to limited broadband frequency resources and the high cost of investment, shared network implementation among providers is required for public safety;

3. Also, compared to older, narrowband systems, LTE networks have a smaller effective range because they operate at higher frequencies, have larger noise bandwidths, and lower transmitting power levels. Therefore, PS-LTE networks require about four times more base stations than a narrowband system for the same number of users to achieve similar coverage;

4. The Chinese private LTE standard needs further testing of connections between terminals and the network and of interconnections between networks, as well as further study of the industry requirements for the different types of data and voice dispatching services.

4.4.1.3 South Korea (2014–2017) [26] [27]

Overview: In 2014, after the Sewol ferry capsize in which response efforts were hindered by a lack of interoperability from responding agencies, South Korea committed to building a public safety LTE network by 2017. The network will be a private, dedicated network used by approximately 200,000 users from 324 agencies including police, fire, EMS, Coast Guard, military, provincial administrative offices, electricity, gas and the forest service.

In 2016, Samsung introduced the world's first end-to-end PS-LTE portfolio based on 3GPP standards, and has since begun to replace existing analogue wireless technology and to ensure that all features concerning voice (individual, group, emergency, priority calls, and broadcast), video (video meetings and closed circuit television passenger monitoring), and data (control signal and large data file transfer) services can be integrated. Implementation is coinciding with the creation of LTE networks being deployed by railway and maritime interests, being planned separately. The ultimate goal is for PS-LTE technology to eventually enable "intelligent disaster prevention," as the technology develops to a level where it can detect elements of danger through automated monitoring and analysis of natural disasters that threaten public safety, such as tsunamis, floods, forest fires and earthquakes.

Parameters: The South Korean government provided a network frequency band of 718–728 MHz uplink and 773–783 MHz downlink (band 28), the standard frequency for the Asia-Pacific Telecommunity band plan APT-700. In 2015, South Korea piloted PS-LTE in three cities with 205 base stations and 2,496 handsets. Ultimately the network will comprise about 12,000 base stations and around 200,000 mobile stations, including fixed mobile stations, vehicle-mounted radios, smartphones and two-way radios, in eight mandatory areas.

In 2016, Samsung launched the network with a demonstration where 20 departments from eight fields, including medical, police, fire protection, military and government services, used the same PS-LTE network deployed by Samsung and responded in accordance with the standard operating procedure [28]. A volunteer called 911 and a responsible organization then reported the situation to all relevant groups instantly through video-calling or HD group-calling, after which every organization performed their own rescue operations. For this test and the launch that followed, Samsung provided 700 MHz base stations, a virtualized core solution including key PS-LTE features such as PTT, and rugged-type smartphones that have walkie-talkie capabilities and are water- and dust-proof.

In 2017, Samsung tested mission-critical push-to-talk (MCPTT), an international standard set by 3GPP that enables thousands of devices to be connected at once to transfer video, images and voice simultaneously using multicast technology. MCPTT-based services ensure reliable communication for multiple users through other PS-LTE key features such as Group Call Service Enablers, LTE broadcast, Voice-over-LTE, and Device-to-Device communication.

Lessons learned:

1. The government's financial commitment to supply PS-LTE to the country as a whole has been USD $880 million to deploy the network and USD $900 million for 10 years of operation;

2. Band 28, which is being used by South Korea for its PS-LTE network, is becoming a common commercial LTE band globally. As it already has a good device ecosystem, it is considered an attractive band to use for PS-LTE implementation [19];

3. To provide competition, South Korea's three commercial carriers were able to bid on the contract for the network, which comprised three separate bidding phases—pilot, extension and completion phases. As well, a number of telecom providers have won parts of the project and are currently building and testing control centers, radio stations, and handsets;

4. The response time of Samsung's dedicated MCPTT application was 300 milliseconds, which is faster than standard LTE voice applications (600 milliseconds) and can prioritize key figures such as the president, the authority in charge of an entire scene, and those responsible for reporting situations, and allows for seamless connectivity unaffected by the environment;

5. The network must ultimately address interoperability with different vendors and legacy proprietary equipment such as Very High Frequency (VHF), Ultra High Frequency (UHF), and TETRA. Radio access network (RAN) sharing will also be accommodated;

6. In 2017, Samsung's LTE-Railway solution was successfully launched on a South Korean metro line, demonstrating for the first time that LTE can be operated on a high-speed train travelling as fast as 300 kilometers per hour;

7. An aggressive timeline of deploying a PSBN appears to be achievable if partners are committed to it;

8. Undertaking a graduated region-by-region roll out, rather than attempting to cover a country in one fell swoop as UK, may also be a way of mitigating risk;

9. There appears to have been a change in approach, however, with an original commitment to begin deploying in rural areas that do not currently have a unified network before extending into cities. Ultimately Seoul have been first to obtain coverage, presumably indicating the relative ease of providing as well as the higher return on investment [29];

10. The aggressive timeline placed phase one to begin in 2015, phase two to roll out in 2016 and the completion of phase three in 2017. At that point all eight provinces, one self-governed province, seven metropolitan cities and one self-governed city that make up South Korea will have had access and coverage on the network. As of the writing of this report, it is unclear whether South Korea has met these targets.

4.4.2 Europe

4.4.2.1 United Kingdom (UK) (2011–2016) [30] [31]

Overview: In 2011, the Government set up the Emergency Services Mobile Communications Programme to look at options to replace a TETRA system provided by the Airwave Company, which was acquired by Motorola in 2016. The hope was to have an interoperable data capability for emergency services. However, because of the lack of dedicated public-safety spectrum allocation and funding within Europe, the UK and other European countries have had to build alternative models of public-safety LTE deployment. In the UK, the choice has been to use resources from commercial LTE networks. Instead of a dedicated public service network, UK chose to contract development of an Emergency Services Network (ESN) to Motorola and the commercial 4G mobile data network operator EE (since acquired by BT). The government had hoped that disaggregating the ESN into multiple contracts and using commercial technology would provide scope for frequent re-tendering to take advantage of technological improvements.

EE has completed system testing to prove the prioritisation technology would work and that during an emergency its network would be able to prioritise all 300,000 emergency service users if necessary. Motorola is meanwhile developing devices with dual-mode capabilities, including voice PTT. Other planned applications include biometric fingerprint identification, facial recognition, and crime scene readers. Voice over LTE (VoLTE) has now been switched on in a number of cities, including central London, and the ESN as a whole has been promised to be country-wide by the end of 2018. The government has published a parliamentary review that reflects significant concerns that this deadline will not be achieved. Public safety agencies are particularly concerned that they will be shunted over to a commercial system before it can adequately fulfill their mission critical requirements.

Parameters: Work is ongoing to expand coverage of the ESN network from 74% (EE's current LTE coverage) to 97% coverage, including in remote areas and in the London Underground where access is hard to achieve. The company is building out its network to comprise some 19,000 macro sites and some smaller sites. Technical options to close gaps in remote areas are being evaluated such as the use of portable masts. The intent is to have high levels of coverage for major and minor roads, outdoor hand portable devices, marine coverage, and Air to Ground coverage to 12,000 ft. Coverage will be comprised of a number of different elements that need to mesh into one seamless network run by EE, including:

- EE's main commercial 4G network. EE won some 800 MHz spectrum in the 4G spectrum in 2013, and is now rolling that out to its sites;
- Extended Area Services for hard to reach areas of the UK where new sites are to be built under separate contracts and which will be equipped with EE base stations and connected with the main station via backhaul or fiber or microwave wireless mini-hops, and managed through separate contracts. Base stations will also be used for EE's commercial operations, with those funded by the government also available for other operators;
- Air-to-Ground communications achieved via 4G in the 3.2 GHz band;
- London Underground communications achieved via 4G cards in the Wi-Fi access points or separate 4G base stations alongside with coverage back out to the road as well as via antennae through the tunnels;
- Connecting shopping centres and rail stations and other large venues via 4G small cells and distributed antenna systems solutions or home routers integrated into the macro network;
- Crossrail;
- Marine coverage up to 12 nautical miles;
- Special coverage solutions, including small cell mesh networks with dual exits and in-band backhaul, networks-in-a-box, and repeaters mounted on airmasts, weather balloons, tethered unmanned aerial vehicles (UAVs) connected with power cables and optical fibre, helicopters, and remotely operated underwater vehicles.

EE is building a separate core network dedicated to ESN users and able to give priority to emergency services traffic, although it will share the same spectrum and backhaul. EE is also building in extra layers for capacity, taking advantage of new technologies such as carrier aggregation, which combine disparate bits of spectrum to provide more throughput capacity to meet traffic demands. The network still needs to be made ultra-reliable and incorporate new mission critical features and functionality being written into LTE standards 3GPP Release 12 and beyond, which will enhance and support security, allow prioritization, deliver high availability, and eliminate latency in voice communications that could lead to distorted messages. Testing and assurance to give regions an idea of the coverage they can expect on ESN are being provided through the triangulation of three approaches: drive testing; app-based solutions that measure where end users go and report back signal strength, coverage and quality in real time; and geolocation statistics from the network, including historical data, for infrequently used routes.

Lessons learned:

1. It is risky to attempt to form an end-to-end, integrated, tested, commercial LTE system that is intended to scale up to complete coverage of the country in one fell swoop. Concerns are rising that the ESN will have to be run in parallel with Airwave for some time, especially in some parts of the country, adding costs. To prepare for this eventuality, bridges are being built to talk across the two systems;

2. Resistance to adopting PS-LTE is particularly strong in markets such as the UK where trunked radio networks have not been fully amortized, culminating in the need for multi-mode devices to enable a smooth migration to PS-LTE though with the additional cost of maintaining parallel networks;

3. However, an advantage of using a commercial network/spectrum is that public safety users will access services via the same LTE carriers and base stations as commercial users and they will be able to use existing commercial devices. Meanwhile, special ruggedized devices that will also be required can be developed based on chipsets that support existing commercial LTE bands [19];

4. Prioritization of the ESN in an emergency will be automated and not likely to lead to diminished service for public using the network, and if this is the case additional spectrum can be allocated;

5. The UK regards 4G as a much more stable standard than 3G and comes with a roadmap that will enable EE to increase coverage, capacity and resilience as 4G develops, and to evolve to 5G in 2020. High data transition speeds of up to 1 gigabyte per second (Gbps) capability are on the horizon;

6. Competitive pressure and multiple supplier solutions in the awarding of commercial contracts for LTE management can ensure that the public safety sector obtains the best possible deal, service, and upgrades;

7. Equipment specifications created by early equipment developers should not exclude other providers but be standards-based;

8. Likewise, if multiple carriers are going to be involved in service delivery, early engagement is important, as it is cheaper to build a mast to carry multiple networks rather than to adapt mast design at a later date;

9. Delays can occur in the timely creation of standards and fulfillment of requirements for all of the new applications required, including mission critical video over LTE and mission critical data, requiring the use of pre-standard solutions in the meantime;

10. Contract reviews and likely new legislation is required to ensure providers have the right to access sites to fix disabled equipment, do preventative maintenance, and proactively install generators in advance of bad weather. Currently, permission to access sites is frequently obstructed by landlords;

11. Obtaining permissions to work in national parks can also present a special challenge;

12. Subway systems and tunnels present particular difficulties for LTE communications, requiring special coverage solutions for railways including tunnel coverage and infill coverage in railway cuttings;

13. It is challenging to reduce dropped call rates of voice over LTE to zero. To beef up transmission resilience, EE is also looking at implementing multiple routes back to the network to connect every base station to the core network comprising wireless links and satellite and leased links. As the UK suffers from 60,000 power cuts a year, developing reliance for the network requires installing many fixed and mobile generators at its sites. Independent battery backup is additionally required to provide time for repair teams to arrive, which can take up to four hours;

14. EE has also made a detailed study of flood plains in the UK that have a 1-in-1,000 years risk of flooding and is acquiring a fleet of hundreds of rapid response vehicles to defend radio sites in areas that fail due to flooding;

15. Satellite connections appear viable for remote area connection to many sites where there is no backhaul, such as the Scottish Highlands, for temporary coverage solutions, and for back-up if a main solution fails. While it normally takes 480 milliseconds to complete a round trip via satellite, recent EE proof of concept trials undertaken with partners nonetheless achieved 100 megabyte (MB) speeds. Testing is being done to deploy small cell solutions on lighthouses that mesh up and provides coverage to ferries that also carry a small cell on board. This solution may be used to connect UAVs as well, providing a solution useful for fire services;

16. In the long run it is hoped to have direct mode operation radio-to-radio communication without going through the main network, which is a key function in TETRA, but for which 4G was not originally designed. It is unclear whether handsets will have this functionality by the time of the transition. Back up ideas may be required, such as a dual TETRA and LTE devices, or alternatively devices using Time Division Duplex (TDD) or Global System for Mobile (GSM) spectrum;

17. The elimination of gaps in LTE push-to-talk voice communication—to ensure, for instance, that a “don’t shoot” command is not heard as “shoot”—has been validated in a lab environment but not in the field.

4.4.2.2 Finland (2014–2017) [32] [33]

Overview: Finland in 2014 decided to have critical voice and broadband data delivered by a government-controlled hybrid of dedicated and commercial LTE networks by 2030. A staged process has been outlined as follows:

1. Continue to run critical voice and messages in the narrowband network, and begin to run high-speed non-critical, but secure, data in the commercial broadband network;

2. Expand LTE offerings into a dedicated broadband radio access that provides mission-critical voice over LTE service in chosen locations;

3. Connect the LTE voice network to the TETRA network so voice services are available in both networks, with LTE voice up to the level data providers can offer;

4. Dismantle TETRA radio access once broadband service availability and reliability across the country meets public safety's requirements.

Parameters: Instead of being hosted on a dedicated spectrum, public safety agencies will be hosted along with industrial clients by network carrier Ukkervot in the 450 MHz spectrum, which is considered superior to higher frequency bands for Nordic countries [34]. To begin progress towards implementing LTE for public safety agencies, Nokia in 2017 trialled mission-critical voice communications that prioritized first responders over other data traffic. Field trials using the Nokia LTE RAN infrastructure were able to ensure network prioritization of public safety workers in a variety of situations, including a hockey game.

To begin progress towards stage 3, Airbus Defence and Space have developed a mobile core network solution called "Tactilon Suite" to manage subscribers in both narrowband and broadband networks, helping to establish a secure, hybrid Mobile Virtual Network Operator network. The multi-network approach is intended to offer public safety subscribers a one-stop shop for secure broadband capacity, where each device gets the best available connection [35].

Lessons learned:

1. A staged approach to conversion from LMR to LTE voice can support users and integrate capabilities while networks evolve to full data coverage, including in hard-to-reach places;

2. According to a Nokia press release, the 2017 test results showed public safety communications can be prioritised over a public LTE network even when that network is extremely busy;

3. According to Airbus, the Mobile Virtual Network Operator approach will allow public authorities to take advantage of existing commercial broadband services to obtain broadband applications and services anywhere in Finland, without requiring new infrastructure.

4.4.2.3 France (2015–2017) [36] [37] [38]

Overview: France is working on deploying a Public Protection and Disaster Relief (PPDR) network by 2019. France's total bandwidth allocation for public safety is less than in US & Korea and composed of two relative narrow slices. France has made a different choice than the UK to deal with the lack of dedicated public-safety spectrum allocation and funding within Europe, sharing resources with commercial partners by building out a national 4G LTE network at the same time as its PPDR. Spectrum is being auctioned in the 700 MHz band with strict obligations that will support the PPDR, including obligations to provide coverage equivalent to what is currently achieved in the 800 MHz band with regard to rural areas, to improve the quality of 4G services in these areas over time, and to prepare for the potential development of 5G services on these bands. Also included are obligations to improve mobile data availability onboard trains.

Obligations of providers to support the PPDR will ensure that the network is adapted to the specific needs of the PPDR and that the PPDR will take maximum benefits from the commercial LTE ecosystem. This approach addresses the problem that network upgrades (such as additional cell sites) are needed to meet the service demands for public safety, but the costs for these upgrades cannot typically be justified by public safety service revenues [18].

Specific technology solutions are being developed by Airbus under the title Long Term Evolution for Professional Mobile Radio (LTE4PMR), which is creating the base station, the core network, and the terminal chipset enabling the deployment of mobile broadband secure communication networks in various frequency bands.

Parameters: For national LTE, six blocks of 2 x 5 MHz (that is, a "pair" of 5 MHz frequency allocations) are on offer, and a single candidate cannot acquire more than three in total or hold more than 2 x 30 MHz of low frequency spectrum in total across the 700 MHz, 800 MHz and 900 MHz bands combined. These include 2 x 5 MHz and 2 x 3 MHz in the 700 MHz band (698–703 / 753–758 MHz and 733–736 / 788–791).

Some LTE technology is being designed to implement services on the 400 MHz band. Airbus Defence and Space, France's TETRA supplier, has already developed a multi-standard base station platform in the 400 MHz band that combines professional mobile radio (PMR) with LTE technology. The LTE4PMR platform will offer MCPTT, data, and video transmissions. These applications will be adapted to address actual field use cases outlined by the end users and to interact with existing communications systems. Also in testing is direct mode operation that will allow two devices to communicate without network radio infrastructure. An evolved universal terrestrial access network operation for public safety is further being tested that will allow an LTE EUTRAN to operate with limited to no backhaul and still offer MCPTT.

Lessons learned:

1. Having data providers agree to build out and service an PS-LTE as an obligation for using LTE spectrum they have obtained at auction offers a prospective way to broaden coverage and service for public safety communication at relatively low cost;

2. To provide safe testing grounds for new technology, the country has allowed the country's broadcasting services to create small isolated tactical experimental networks —called "bubbles"—in some geographical areas;

3. As the 700 MHz allocation is not expected to cover all of France's PPDR needs, there is a plan to use additional resources at 400 MHz, which is where the current TETRA network for public safety sits. Continuing to use standard radio frequencies at the 400 MHz will also help to mitigate the higher costs of supplying coverage to some hard-to-reach locations network at 700 MHz;

4. Using unusual bands as France is doing with its 5 MHz slice at band 68 could reduce the availability and increase the cost of devices;

5. Suppliers are complying with Release 13 of the 3GPP, which is responsible for LTE standardisation and is developing features specifically targeted towards public safety. These include prioritised and preemptive network access to ensure mission critical services continue to function during emergencies and specific service capabilities such as PTT and group communications [18].

4.4.3 South America

4.4.3.1 Chile (2015) [39] [40]

Overview: In 2015, Chile reserved the 703–713 and 758–768 MHz bands of 4G spectrum to emergency communications and Motorola Solutions first demonstrated its solutions and devices for mission critical communications on public safety LTE networks in Santiago.

Parameters: Motorola's demonstration included the Motorola Solutions LEX L10 Mission Critical handheld smart computer, which provides personnel with information when and where they need it, with the security and control of its own network guaranteeing the confidentiality of the information. It also featured the Real Time Video Intelligence application, which allowed users to view live video broadcasts on LTE devices and, when integrated with the Motorola Solutions MVX1000 recording system, allowed officers to broadcast live video from their vehicles to other users connected to the same application.

The demonstration also included Motorola's interoperable and secure PTT Solution that allows users to select a conversation group, push a button and talk to users on other LTE devices or devices with other communication standards, enabling the establishment of quick communications between the different systems, frequencies and devices used by different security forces and emergency agencies.

Lessons learned:

1. The demonstration features different critical situations that first responders may face to illustrate the benefits that public safety LTE technology offers to improve prevention, management and resolution of crime and emergency events.

4.4.4 Middle East

4.4.4.1 Qatar [41]

Overview: The Qatar public safety administration has deployed a private 800 MHz LTE network to complement its existing TETRA network with broadband applications.

Lessons learned:

1. Early experience indicates considerable additional value for its users in LTE;

2. However, because the underlying technology has not been designed for mission-critical operations, it is currently not recommended for such use until the relevant standard bodies complete their work over the coming years. Qatar will accordingly continue to use its TETRA network for mission-critical voice and data until such time as LTE is able to offer similar Quality of Service as TETRA, which it expects to take as many as 10 more years [42].

5 Analysis: themes in the lessons learned

This section analyzes themes emerging from the lessons learned that could bear on the deployment of a PSBN in Canada. Taken together, these themes firstly offer perspectives on the prospective value, challenges, and mitigating potential offered by PSBN as a whole to public safety agencies. Secondly, the themes offer insight into the special challenges and mitigation opportunities raised by the different implementation models for PSBNs currently being deployed around the world, namely: dedicated, commercial, and hybrid models.

5.1 Benefits, challenges, and risks of PSBNs

5.1.1 Benefits

The theme that emerged most strongly was the significant benefits that broadband data capabilities and applications could add to public safety activities. These included enhanced information exchange, situational awareness, and operations from the real-time transmission of incident-critical data via VoIP, email (with and without attached images), ability to view and broadcast video including live-streamed unmanned surveillance video and video conferencing, to scan and query radio frequency identification tags, and to use mapping applications that can generate a common operating picture and guide operators to problem sites. Other cutting edge uses that public safety data networks are anticipated to enable include public safety-focused IoT solutions; wearable sensors and cameras for police and firefighters; and camera-equipped drones and robots. Broadband data applications can also enhance interoperability across agencies and jurisdictions, which radio systems such as LMR and TETRA cannot as easily provide. The most cutting edge experiments run in South Korea enabled thousands of devices to receive video, images and voice simultaneously. Some device developers are even beginning to develop direct mode operation for LTE that will allow two devices to communicate without network radio infrastructure (Samsung).

Overall, it appears that transitioning public safety communication and situational awareness capabilities to LTE will improve the continuity and reach of public safety communications while improving information integrity, information accuracy, situational awareness, timely diagnosis and response capabilities, and workload efficiency. Ongoing benefits are foreseen for improving prevention, management and resolution of crime and emergency events, and for further transitioning to increasing levels of coverage and resilient communications as 3G evolves fully to LTE (4G) and thereupon to 5G.[2]

[2] While quantifying these benefits is challenging, a London School of Economics study assessed the value of a PSBN for the EU as equivalent to that of 34 billion Euros (51 billion CDN) for 500 million people, or roughly CDN $100 per person. This estimation was made based on criteria of safety, efficiency from enhanced safety, operational efficiency, the use by traffic police, and a reduction of mortality by ambulance services. The study further inferred that the value of the PSBN is roughly 6 times the opportunity cost lost by not auctioning off the same portion of the spectrum (6 billion Euros/9 billion CDN). At these rates of value, one might infer that the value of the PSBN in Canada might be $3 billion CDN, reversing the ratio with the opportunity cost, due to our lower population but presumably highly valued spectrum. However, as many of the economic criteria in play in assessing the value of a PSBN in Canada are likely to be different than those in Europe, a separate economic analysis beyond the scope of this study would have to be conducted to obtain further insight into this question.

5.1.2 Challenges and risks

Despite the value of PSBN, several general challenges for implementation have been observed across the board, in terms of completing, testing, and validating networks and technologies and in terms of achieving uptake and capability in their use by public safety agencies.

Most lessons learned have confirmed that the process of testing and guaranteeing LTE applications for mission critical work is likely to be prolonged. Delays are arising in the creation of standards and fulfillment of requirements for all of the new applications required in a public safety data ecosystem, including mission critical data and mission critical video over LTE. Even after network build-out completion, there are concerns that PSBNs may provide insufficient coverage in rural areas, and that they may not be robust in poor weather scenarios, including disaster scenarios, that are notorious for reducing or even eliminating data coverage, but in which public safety agencies will need to operate. As the tests and deployments covered in this document tend to be highly planned, it is likely that the threats presented by such contingencies have not been fully encountered and engaged with by PSBN planners and carriers.

Further, LTE systems are generally observed to be more complex to implement and more laborious to use, requiring strategies for mitigating technology risks. New LTE-enabled applications are typically initially demanding for first responders to use and the cognitive load may impact response capabilities if adequate training and exercising is not provided.

5.1.3 Mitigating challenges and risks

Some recommended technology risk mitigation practices observed in the CAUSE II, III and IV experiments include engaging the emergency responder community to identify requirements for tools and applications; engaging the vendor community to troubleshoot and solve integration issues; modifying existing standard operating procedures for first responders to accommodate the effective sending and receiving of data; and providing training and collaboration opportunities to managers as well as operators to gain familiarity with incoming technology features and functionalities.

As will be discussed later in this analysis, certain PSBN models—namely hybrid and dedicated PBSN—appear to allow more scope and type for these types of practices to unfold.

5.2 Choosing among PSBN models: dedicated, commercial, or hybrid

5.2.1 Short term vs. medium term

In the short term, small local PSBNs deployed on an event-by-event basis have provided significant upgrades over what was obtainable through commercial contracts, in terms of ensuring reliable and fast network access and bridging the different systems, frequencies and devices used by different security forces and emergency agencies. In a U.S. test during a large, densely populated event, dedicated LTE service was observed to be two-to-three times faster than commercial networks could provide at the time and place, and to permit real-time video streams to be maintained.

A large number of medium term problems were, however, foreseen for PSBNs that hoped to "go-it-alone" as distinctively administered networks, as can be seen in Section 6.2.2. On the other hand, as is reviewed in Section 6.2.3, commercial networks that are currently being deployed are raising their own concerns, to which dedicated and/or hybrid approaches to building out PSBNs appear to offer solutions.

5.2.2 Concerns regarding dedicated PSBNs

5.2.2.1 Resource requirements for managing and upgrading the network

With respect to dedicated PSBN networks, distinctive challenges arising from relying on public resources were seen as making dedicated PSBNs harder to upgrade and scale. For PSA-hosted equipment, it can be expensive to ensure that public safety agencies have the required cloud server space and physical space for equipment. More importantly, agencies need staff capable of configuring and operating components of the network, including dedicated technical personnel to manage the daily operations of the LTE network and drive continual improvement—ideally with the support of enhanced performance data on the health of the network and the user experience. Implementing LTE applications (especially several at once) can also lead to a requirement for considerable technical support to integrate the applications with the technology. There is an ongoing need to reconfigure the network, for instance before major events, to enable appropriate parties to access the network tools.

5.2.2.2 Bandwidth limits

Frequently noted was that the bandwidth allocations for providing dedicated PSBN capabilities would be substantial. Significant bandwidth as well as scope within the system to increase capacity and data allowances will be required in PSBN networks to prevent lags or crashes of the system with multiple applications running simultaneously in real-world events, especially when sharing video. In one early trial, 10 MHz of spectrum was insufficient to meet incident requirements such as the sending of videos, which tended to freeze and break up due to inadequate capacity for the uploading, downloading, and streaming. The addition of voice applications were predicted to stress bandwidth requirements further. In some instances it was suggested that even the 20 MHz in the 700 or 800 band typically allocated for designated PS-LTE networks may be stretched. Some solutions proposed for ensuring bandwidth adequacy include reducing edge-of-cell-situations through the use of overlapping cell coverage (East Bay). Another solution is to maintain additional voice resources and applications that function in the 400 MHz band, where LMR systems typically work (France).

A DRDC CSS (2011) study found that "2x10 MHz of bandwidth would…support the data communications needs of first responders during incidents of moderate to moderately severe intensity" in Canada (p. 2). While the analysis did not specifically analyze the impact of future developments such as "IoT and 5G effects," it anticipated that the additional capacity that upcoming network developments such as 5G would contribute would more than cancel out the additional demand for data that upcoming technologies such as IoT would require [43].

5.2.2.3 Cost & cost-effectiveness issues

Other problems foreseen for PSBNs included the cost of dedicated systems, which were viewed to be high. After initially allocating spectrum for a PSBN, Australia has opted for a model that would use existing commercial networks to save an estimated $4 billion of an anticipated $6.2 billion cost of building an exclusive national mobile communications network for public safety agencies using set-aside spectrum. Although South Korea foresees much lower costs, less than $1 billion to deploy and less than another $1 billion for 10 years of operation, this might reflect a special governmental relationship with the provider, Samsung, and/or the smaller geographical region that must be covered. The cost-effectiveness of dedicated PSBN has been challenged, with observations that public safety service revenues alone cannot justify the network upgrades and cell site additions needed to meet the service demands for public safety. One reason offered is that compared to older, narrowband systems, LTE networks have a smaller effective range, requiring about four times more base stations than a narrowband system for the same number of users. Continuing to use standard radio frequencies in the 400 Mhz band is seen as helping to mitigate the higher costs of supplying coverage to some hard-to-reach network locations at 700 MHz. (France). Allowing a range of business units to operate on the PSBN is another strategy that has been seen as important for leveraging its costs (Calgary, Australia).

In the US, partner mobile operators will provide FirstNet consumers prioritized coverage on Band 14 in urban areas and prioritized access on commercial networks in rural areas to reduce costs.

5.2.2.4 Equipment options

Concerns have arisen that dedicated PSBN users will be more limited in their ability to access equipment and technology in comparison with users of commercial spectrum, who will be able to use existing commercial devices because they will access services via the same LTE carriers and base stations as commercial users. Even special ruggedized devices required by public safety operators can be developed based on chipsets that support existing commercial LTE bands. By contrast, as the Band 14 dedicated to PSBN in North America will be specific spectrum for public safety, users will not be able to use products from the existing commercial LTE ecosystem. Nonetheless, the North American market is anticipated to be large enough to attract device and network infrastructure vendors to develop products for it. Likewise, Band 28, which is being used for Public Safety LTE in South Korea, is becoming a common commercial LTE band globally and it already has a good device ecosystem. Certainly, using unusual bands for public safety, as France is doing with the 5 MHz slice (band 68) could reduce the availability and increase the cost of devices. To expand the range of public safety options in small markets, suppliers contracted in hybrid arrangements are complying with Release 13 of the 3GPP, which is responsible for 4G LTE standardisation and is developing features specifically targeted towards public safety.

Whether a dedicated, hybrid, or commercial model is used, tailoring PSBN networks and applications to meet operational requirements and ruggedizing and configuring devices for public safety use is likely to be somewhat time consuming. One lesson learned (BC) to ease the transition to public safety LTE is that user equipment such as hand-held devices should be capable of being debugged, including diagnostic and reconfiguration capability, to avoid crashes and overcome problems introduced by new system demands. Another is that equipment specifications created by early equipment developers should not exclude other providers but be standards-based. In general, it has been observed that more extensive standardization and certification of devices and applications is needed, as applications such as PTT do not typically operate on different devices or networks or recognize devices operating on other applications, creating interoperability risks.

5.2.3 Concerns regarding commercial PSBNs

Dedicated PSBNs were not alone in raising concerns and problems. In particular, the UK, which has contracted entirely with commercial partners to build their public safety network using their spectrum resources, appears to be encountering significant difficulties and setbacks deploying a wholly commercial PSBN. As well, public safety agencies in the UK and Australia appear to be resisting commercial models of PSBN, expressing concerns about technology and coverage letdowns by commercial providers in mission critical operations. In a more subtle way, public safety agencies have signaled other concerns about commercial models regarding costs, implementation timelines, and less effective engagement of the Public Safety community potentially inherent in these models.

5.2.3.1 Rigid timelines

The most significant problem in the UK appears to be the deployment timeline of three years, which, while similar to South Korea's implementation timeline, is facing lags substantial enough to have led to the launch of a parliamentary inquiry. In particular, concerns are being raised that trunked radio and LMR consumer systems will ultimately have to continue to run in parallel because the latter will not be at a level of operational readiness across the country when the trunked radio contract is set to end, at the end of 2018. Because the UK is implementing a commercial model for its PSBN, contracts oblige it to transition out of TETRA at the end of 2018, when the LTE model is supposed to be ready, or else to incur significant costs to run the two systems in parallel. While South Korea is on track to achieving a three-year deployment timeline, it appears to be benefitting from a small geography already well-mapped by LTE networks as well as highly committed partners in Samsung, which it has contracted to provide dedicated PSBN spectrum.

5.2.3.2 Coverage limitations

The most typical concern regarding commercial network implementation models is coverage limitations. Essentially, many public safety agencies and local government workers in regions where commercial and hybrid PSBN solutions are being deployed lack confidence that rural regions will be covered by such networks. The Police Federation of Australia continues to express that relying on commercial operators will not address coverage blackspots that threaten first responders' ability to communicate in remote areas because it is commercially unviable to extend network capacity into these regions. Likewise, in the UK parliamentary report and the U.S. Senate hearings, significant concern was expressed about the ability of providers to provide coverage to rural areas. In this regard the UK provider, at least, appears to be working hard to foresee and overcome obstacles, with satellite connections being planned to cover temporary coverage solutions and back-up if other solutions fail.

Additional concern is expressed about whether commercial providers will be committed and able to sustain PSBN coverage in disaster situations where it is especially needed, as well as during power outages. The UK suffers from 60,000 power cuts a year, and developing reliance for the network requires installing many fixed and mobile generators at its sites. Independent battery backup is additionally required to provide time for repair teams to arrive, which can take up to four hours. EE has additionally undertaken a detailed study of flood plains in the UK that have a 1-in-1,000 risk of flooding and is acquiring a fleet of hundreds of rapid response vehicles to defend radio sites in areas that fail due to flooding. To increase transmission resilience, EE is also looking at implementing multiple routes back to the network to connect every base station to the core network comprising wireless links, satellite and leased lines.

Other zones raising concerns related to coverage are non-vehicular transportation systems and routes, though recent tests suggest these may be largely possible to overcome. Providing coverage to subway systems and tunnels requires infill coverage in railway cuttings, while the UK plans to use mesh solutions on lighthouses to cover marine locations traversed by ferries. Recent tests in a South Korean metro line have meanwhile demonstrated that LTE can be operated on a high-speed train travelling at 300 km/h.

5.2.3.3 Access, prioritization, and security of PSBNs

Particular concerns of public safety agencies pertain to access, prioritization, and security of public safety communication on commercial LTE networks. Some early FirstNet tests have found quality of service priority and pre-emption techniques to function inconsistently. More recent tests of these capabilities are, however, more promising—at least as they are being reported by commercial technology providers. Telstra's tests in Australia have shown that that stadiums filled to capacity are no longer an issue for emergency services communication via the mobile network. Finnish test results showed public safety communication can be automatically prioritised over a public LTE network even when that network is extremely busy in an event, with additional spectrum available to be allocated if public access to the network becomes constricted. Motorola likewise touted the confidentiality of information passing across its trial network in Chile, though this type of capability has not likely been thoroughly tested at this point against real world security threats.

5.2.3.4 Costs expected to be borne by public safety agencies

Some of the resistance by public safety agencies to commercial PSBN appears due to the costs they are expected to assume as they form their own contracts with commercial providers. For instance, it has been observed that resistance to adopting PS-LTE is particularly strong in markets such as the UK where trunked radio networks have not been fully amortized. Likewise in Australia, where Telstra has been developing their LANES system to provide mission-critical data for public safety agencies as well as enterprise customers, no emergency agency customers have yet subscribed. This may suggest that the costs Telstra is charging are seen to be too high and are presenting a barrier to adoption, or alternatively that public safety agencies remain concerned about the adequacy of the commercial driven model to their requirements.

5.2.4 Concerns common to both dedicated and commercial networks

5.2.4.1 Deployment demands and difficulties

Deployment difficulties were common to both dedicated and commercial PSBNs in the process of expanding national network access to levels sufficient to permit public safety applications. Permission to access equipment host sites is frequently obstructed by landlords, so that service level agreements with hosts of sites, and even new legislation, are believed to be required to ensure providers have the right to access sites of public safety broadband equipment to fix disabled equipment, do preventative maintenance, and proactively install generators in advance of bad weather. In both dedicated and commercial models, the need to use public assets for site locations and network connectivity requires the sometimes delicate negotiation of access to public safety agencies and other public entities of places such as national parks. Design of the PSBN additionally needs to observe locally acceptable mounting heights, as it was seen in B.C. that permitting for high antenna structures can be laborious.

5.2.4.2 Coverage

Concerns about coverage in rural areas are also looming where dedicated and hybrid implementation models are being pursued. LTE coverage gaps in mountainous and rural areas of several countries (China, France) are expected to persist, leading to those country's plans to continue deploying radios at lower frequencies. In Canada, B.C. tests showed that most requirements for relatively continuous PSBN communications in remote areas of Canada can be accurately projected and adequately supplied.

However B.C.'s tests also found that Internet services may be inadequate for providing system backhaul for PS-LTE in some remote areas, with standard modems and routers unable to handle the additional traffic that can be introduced by first responders using LTE applications such as image and video sharing. In cases where there is no existing or viable backhaul, satellite connections and virtual private networks connected to dedicated servers could be required, though satellite reception may not be adequate for applications requiring extremely high performance. A FirstNet pilot also revealed that unlicensed microwave radio services can augment backhaul links, though these may increase operational risk if they deployed without redundant solutions.

5.2.4.3 Mission Critical Push-to-Talk (MCPTT) over LTE

When it comes to technology readiness, PTT over LTE devices is typically expected to not be ready in the short term to support mission-critical voice communication. This is because the underlying technology was not designed for mission-critical voice and still needs to be standardized for that purpose. In the UK it was found to be challenging to reduce dropped call rates of voice over LTE to zero, though improvements are being obtained over time. The elimination of data packet gaps in LTE push-to-talk voice communication (e.g., potentially leading to an officer hearing a command of "don't shoot" as "shoot") have been validated in the lab but not in the field (UK). As well, because PTT applications on LTE are not standardized, their use is seen as presenting an interoperability risk until relevant standard bodies such as the 3GPP complete their work over the coming years.

For these reasons, countries such as Qatar, Finland, and China are committed to keeping their LMR/TETRA radio networks available for mission-critical voice and low bandwidth data to provide additional safety, security, stability and reliability until such time as LTE is able to offer similar Quality of Service. In some countries, equalizing the quality of PTT over LTE with that achievable over LMR or TETRA is foreseen to require at least a decade. In the meantime, PTT over LTE is seen in places like Texas as a powerful way to communicate non-emergency information and reduce voice traffic on the main LMR security channels, especially while coverage is being expanded across rural areas. Ensuring interoperability between LTE and older radio systems is accordingly being prioritized in many of these countries, which are developing applications to bridge networks so that public safety workers can speak across them. In South Korea, for example, the PSBN is being designed to interface with legacy proprietary equipment such as VHF, UHF, TETRA, and RAN sharing.

Over the long term, it is expected that MCPTT over LTE will become a reality. Innovations are on the horizon such as Samsung's South Korean MCPTT which is already twice as fast as standard LTE, and France hosting tests of a EUTRAN that will support mission-critical push-to-MCPTT over LTE with limited to no backhaul. In the meantime, however, a relaxed and flexible timeline—as seems easier to accommodate in a dedicated or hybrid model—appears helpful for allowing MCPTT over LTE to unfold in a way that does not rush users off of their currently trusted radio solutions.

5.2.4.4 Interoperability, spectrum-sharing, and interference

Interoperability challenges arise with migration to LTE in a commercial system in which LTE networks are contracted by different public safety agencies and operated by individual providers. As has been observed in China, these challenges must be addressed, as shared network implementation among providers is required due to limited broadband frequency resources and the high cost of investment. In South Korea the PSBN is being developed to address interoperability with different vendors; in Australia it is foreseen that achieving interoperability as well as harmonies between public safety agencies using commercial systems will require jurisdictions to agree on common protocols covering matters such as network technology, spectrum, end-user devices, and applications, protocols for sharing information, and protocols for sharing network capacity where capabilities are shared and/or jurisdictions overlap. To solve this problem, jurisdiction-wide implementation entities are recommended to be formed in order to minimise duplication and improve economies of scale.

Even in PSBN implementations that make use of dedicated spectrum for public safety users, such as Band 14 usage in North America, it is foreseen that interoperability issues are bound to arise, particularly across jurisdictions and borders. In this regard, mutual aid agreements and bi-national Concept of Operations for deployable LTE systems and cross-border working groups are foreseen as crucial for strengthening interoperable communication and coordination in events and for identifying and addressing cross-border interference challenges.

5.2.5 Solutions introduced by commercial models (and some hybrid models[3]) relative to dedicated models

5.2.5.1 Efficiency of spectrum use

As the Australian commission of inquiry observed, auctioning spectrum on the commercial market is likely to lead to the most efficient use that spectrum. While the use of spectrum in the hybrid model is not necessarily equally efficient, insofar as the spectrum remains prioritized for public safety use, efficiency can be maximized by allowing commercial providers to use the spectrum for other purposes when it is not needed for emergency communications while agreeing to open up additional spectrum resources for public safety requirements in an emergency. FirstNet, for instance, sees the ability of commercial carriers to share the public safety spectrum as helping to overcome business model challenges involved in bringing PS-LTE to the market in the U.S.

5.2.5.2 Mutual public-private benefits

Hybrid commercial-public models seem to reflect some of the most mutually beneficial relationships between public safety organizations and technology companies, with the latter having scope to design and test exclusive public safety technology and applications useful for public safety agencies, and in in exchange acquiring a testbed for these products with a view to being able to export them to other markets afterwards (South Korea: Samsung, France: Airbus; AT&T; U.S. [FirstNet]). To some degree, this mutually beneficial relationship is being achieved in commercial PSBNs as well, especially where a single provider has been given significant access to the public safety market (Nokia, Finland; Motorola, UK). Commercial opportunities for companies to benefit from using countries as testbeds may, however, diminish as increasing numbers of countries enter the global PSBN application and the technology market is reducing chances for providers to be “first out” with a new application.

In the hybrid model, data providers are also obtaining mutually beneficial terms from governments, obtaining concessions to extend their LTE networks in exchange for obligations to build their network in a way that will support the PSBN (France). However, exactly how these obligations are being enforced and/or financed remains unclear.

[3] As hybrid models can adopt characteristics of either commercial or dedicated models, depending on their implementation, this section, and the next, focus on the commercial and dedicated model differences. The authors recognize that each characteristic may be present in hybrid models, depending on implementation, making it difficult to draw conclusions on hybrid models with any certainty.

Regardless of whether purely commercial or hybrid commercial models are used, a number of countries, including UK and South Korea, observed that it is important to have competitive pressure and avoid single supplier solutions in the awarding of commercial contracts in LTE management. It has also been described as desirable to stage competitions for multiple phases of the network production, including pilot, extension and completion phases, as well as for different network regions and technology applications. In Finland, a Mobile Virtual Network Operators approach is intended to offer public safety subscribers a one-stop shop for securing broadband capacity, where each device gets the best connection available from a range of different mobile carriers.

By contrast, in the U.S., the decision by FirstNet to work solely with AT&T on the "opt-in" version of the PSBN has generated resentment from some state representatives for the lack of transparency and accountability in their business proposal. The partnership has also aroused competition from other providers, who have sought to lure states to opt into parallel PSBN implementations, though whether any parallel PSBNs will actually be stood up (e.g., by Verizon), and whether they will represent a real competition for the FirstNet network, remains uncertain. Meanwhile, as has been observed in the UK, if multiple carriers are going to be involved in service delivery, it is important for them to be engaged early, as it is cheaper to build a mast to carry multiple networks than to adapt mast designs at a later date.

5.2.5.3 Relatively easy to expand reach

In theory, hybrid, as well as commercial approaches open up expedited solutions for overcoming difficulties in providing PSBN coverage in rural and other hard-to-reach areas. In France, having network providers agree to build out and service the Public Safety Network as an obligation for using the LTE spectrum they have obtained at auction has been presented as a way to broaden coverage and service for Public Safety communication at relatively low cost. Likewise, the Government of Australia's argument on behalf of a commercial-driven PSBN implementation was that there would be substantial cost savings due to the public safety agencies being able to leverage and share existing commercial network infrastructure, which would give public safety agencies 99% coverage of the Australian population immediately for 3G and 4G mobile broadband services. In Finland as well, public authorities hope to be able to take advantage of existing commercial broadband service providers to access broadband applications and services anywhere in Finland without having to build additional infrastructure.

However, there remain concerns that rural areas may not be as well-served by the commercial model. Whether extensive coverage to all regions will actually be achieved through commercial PSBN deployment models in countries such as Australia and Finland—which, like Canada, have large rural regions extending beyond population centers—is difficult to foresee, and may be an unrealistic expectation.

5.2.6 Solutions introduced by dedicated models (and some hybrid models) relative to commercial models

5.2.6.1 Phased or prolonged deployments

The major problem with the UK's commercial deployment model seems to have been the expectation imposed in their commercial contracts that TETRA system for public safety agencies be fully replaced with a data network across the country in one fell swoop, rather than amid a staged or phased approach. In general, the hybrid model appears to present advantages in the facilitation of staged deployments over a purely commercial model, permitting more contractual flexibility for learning and testing on the ground and changing deployment strategies as lessons are taken up. The more lenient timelines and graduated region-by-region tests and roll outs afforded by the hybrid model seem to allow applications to be tested and improved in smaller, easier to cover areas before they are pushed out to either more urban sites with intensive requirements or, alternatively, to more rural and hard-to-reach sites. To provide safe testing grounds for new solutions, France has allowed the country's broadcasting services to create small tactical experimental networks called "bubbles" in isolated geographical areas before deploying in cities. By contrast, in South Korea, cities were ultimately given PSBN capabilities before rural regions, as was initially planned.

5.2.6.2 Greater time and opportunity for interface between suppliers and public safety agencies

Dedicated and hybrid models of deployment appear to offer advantages over purely commercial models, insofar as they tend to feature more lenient timelines and to promote more extensive and extended relationships between suppliers and public safety agencies. The higher levels of learning, customization, and troubleshooting being permitted within these timelines and models appear to be capable of fostering better trust and update of technologies than are being demonstrated in commercial models. For example, FirstNet's creation of an "Early Builders Network" has reportedly facilitated the creation of user-friendly applications and devices, which allowed users to gain competence and personalize. Other requirements have been revealed in the Canadian-U.S. CAUSE and other Canadian and US tests, which have likewise allowed public safety agencies to experiment with new technologies and give feedback on desirable customizations for serving operational capabilities.

Overall, some examples of recommendations for customizing equipment revealed in these Canadian and U.S. experiences that could help to improve public safety agencies' uptake of PSBN technology and its facilitation of mission-critical operations are as follows:

- Operators on the ground would prefer integrated hands-free devices supporting LMR communications and smartphone functions rather than separate radio and data devices;
- Stable, permanently mounted hardware in cars is needed to allow safe and adept use of the applications while driving or wearing gloves;
- Both handsets and vehicular modems may be required for events with large numbers of users operating on foot or away from vehicle;
- Modifications to applications are required such as better layering of response data from different applications, tools to assign priority levels (e.g., via color codes) and request archiving to reduce first responders' need to monitor multiple applications simultaneously and to help them prioritize needs;
- LTE-enabled information sharing applications should incorporate prompts to acknowledge or confirm the receipt of non-verbal (data) information and to provide follow-up information;
- Multi-party call communication formats in LTE should be networked through dispatch systems to ensure dispatchers are aware of communicated content and share a common operating picture with first responders;

6 Conclusion

Overall, the lessons from PSBN tests and deployments reveal there are likely to be significant long-term benefits for public safety agencies in shifting to a PSBN, but also prospective short and medium term challenges. In turn, these lessons suggest that the different models of PSBN implementation—dedicated, commercial, and hybrid—each hold a range of advantages and disadvantages in terms of maximizing benefits and minimizing risks.

In the first place, the lessons suggest that under relatively good urban conditions there may be relative parity among the different models in terms of their ability to provide adequate and prioritized access to public safety agencies for communication in emergencies. According to the reports of technology and network companies, many common technical concerns regarding commercial and hybrid networks, such as network access, prioritization, and security for public safety agencies seem well on their way to being worked out.

On the other hand, it appears that ensuring coverage for public safety agencies utilizing the commercial model across rural areas and under disaster-type conditions may to be a significant challenge. The willingness of commercial providers to roll out coverage over the entire rural landmasses of countries remains untested amid the early stages of deployment in which most commercial models exist. Likewise, harsh and demanding conditions for LTE have not been tested thus far in pilots and deployments.

Even in the short term, the lessons learned reveal that the choice of models being selected by countries is having indirect impacts on PSBN outcomes insofar as it is bearing on the types of contracts and relationships being created between the public safety sector and commercial entities. Commercial models of PSBN deployment are evidently viewed by countries as ways of offloading the costs of providing coverage and of optimizing the economic efficiency of available spectrum. However, in cases such as the UK and Australia, these savings are apparently being achieved in part through the offloading of the costs of PSBN participation to individual public safety agencies. This offloading of costs to public safety agencies may delay uptake of useful data services and create economic burdens on these agencies. Also in the UK, the contracts are creating obligations to move quickly into a full LTE ecosystem, which is creating anxieties among public safety agencies that some data technologies and network capabilities will not be ready for mission critical work by the time LMR networks are set to be discontinued by national governments.

Commercial approaches also appear to be leading to less flexible deployment strategies and timelines, with less engagement between technology and network companies and the public safety sector, whereby the latter can influence the deployment strategy and the creation of applications. Reduced flexibility in deployment and less pronounced engagement is, in turn, leading to reduced trust and uptake by public safety agencies.

By contrast, dedicated and hybrid models are being undertaken in most cases along extended timelines that are allowing for fulsome customization and testing of networks and applications by providers with extensive engagement with public safety agencies. The relationships and opportunities for engagement afforded by dedicated and hybrid models appear to be providing better opportunities to incorporate PSA needs and experiences and to build trust in the PSBN system.

There are, however, exceptions to this binary opposition, with Finland undertaking a commercial PSBN with committed national suppliers on an indefinite and apparently flexible timeline, and South Korea undertaking a dedicated PSBN on a compressed timeline that nonetheless appears to be flexible in its application. These experiences suggest that making the appropriate choice about an implementation model for PSBN for a given country should also consider the style of executing that choice, and the quality of the relationships built in the process, in order to ensure the ultimate success of the network.

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List of symbols/abbreviations/acronyms/initialisms

3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
ADCOM911	Adams County (Colorado) Communications Center
B.C.	British Columbia
CAUSE	Canada United States Enhanced Resiliency Experiment
CDN	Canadian Dollars
CSSP	Canadian Safety and Security Program
DRDC CSS	Defence Research and Development Canada’s Centre for Security Science
ESN	Emergency Services Network
EUTRAN	Evolved Universal Terrestrial Radio Access Network
FirstNet	First Responder Network Authority
Gbps	Gigabyte per second
GSM	Global System for Mobile
IoT	Internet of Things
LANES	LTE Advanced Network for Emergency Services
LA-RICS	Los Angeles Regional Interoperable Communications System
LMR	Land Mobile Radio
LTE	Long Term Evolution
LTE4PMR	Long Term Evolution for Professional Mobile Radio
MASAS	Multi-Agency Situational Awareness System
MB	Megabyte
MCPTT	Mission Critical Push-To-Talk
MHz	MegaHertz
NFL	National Football League
PPDR	Public Protection and Disaster Relief
PS-LTE	Public Safety Long Term Evolution network
PSBN	Public Safety Broadband Network
PTT	Push-To-Talk

RAN	Radio Access Network
RFI	Radio Frequency Identification
SIM	Subscriber Identity Module
TDD	Time Division Duplex
TETRA	Trunked Terrestrial Radio
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
UK	United Kingdom
U.S.	United States
VHF	Very High Frequency
VoIP	Voice Over Internet Protocol
VoLTE	Voice Over LTE
WiFi	Wireless Networking

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This Reference Document provides a summary of various trials and deployments of Public Safety Broadband Networks (PSBNs), both in Canada and internationally, as well as a survey of lessons learned from these. The content is organized around three broad categories, Canadian trials, U.S. trials, and international trials.

This document provides a general overview of available feedback and guidance based on trials and deployments of PSBNs. The document is intended to serve as supporting material for policy decision-making in relation to the creation of a Canadian PSBN.

Le présent document de référence contient un résumé des divers essais et déploiements de réseaux à large bande de sécurité publique (RLBSP), au Canada et à l'étranger, en plus d'une étude sur les enseignements qu'on en a tirés. Le contenu est réparti en trois grandes catégories : les essais canadiens, américains et internationaux.

Le présent document donne un aperçu général de la rétroaction et de l'orientation offertes en fonction des essais et des déploiements des RLBSP. Il est destiné à servir de document d'appui à une politique concernant la prise de décisions stratégiques relatives à la création d'un RLBSP canadien.