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Broadband Assessment Report
May 2015

State of Colorado
2015 FIS Alpine World Ski Championships
Band-Class 14 LTE Demonstration Network Assessment Report

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EXECUTIVE SUMMARY

The Department of Homeland Security (DHS), Office of Emergency Communications (OEC) supports and promotes the ability of emergency responders and government officials to communicate in the event of natural disasters, acts of terrorism, or other human-caused disasters, and works to ensure, accelerate, and attain interoperable and operable emergency communications nationwide. The Interoperable Communications Technical Assistance Program (ICTAP) provides technical assistance to states and urban areas for voice and data public safety communication projects. OEC/ICTAP works with local, state, and federal interoperability efforts to enhance agencies' and individuals' overall capacity to communicate with one another.

The State of Colorado Statewide Interoperability Coordinator (SWIC) requested OEC/ICTAP assistance with evaluating public safety mobile data devices and applications utilizing a temporary band class 14 (BC-14) Long Term Evolution (LTE) public safety broadband demonstration network at the 2015 Fédération Internationale de Ski (FIS) Alpine World Ski Championships in Vail and Beaver Creek, Colorado (hereafter referred to as the BC-14 demonstration network). This report is a detailed accounting of that evaluation and includes findings, recommendations, and next steps.

Overview

This temporary BC-14 LTE demonstration network is the culmination of several years of combined efforts across multiple layers of government and private industry. Personnel from the Governor's Office of Information Technology (OIT)/FirstNet Colorado (FNC) helped to successfully blend the public/private partnerships formed during the development of the Broadband Technology Opportunities Program (BTOP) grant project in Adams County with the public/private partnerships formed in advance of the Championships throughout the Eagle Valley area. FNC applied for and received a one-month Special Temporary Authority (STA) from the Federal Communications Commission (FCC) (with concurrence from FirstNet as the official licensee) to operate the BC-14 demonstration network from January 17-February 17, 2015. The result was an event-specific private/public consortium of agencies, organizations, and companies dedicated to bringing a BC-14 demonstration network to fruition for the event.

Assumptions/Artificialities

The data reported in this assessment have limited generalizability in several key areas. Attempting to generalize or utilize the data beyond the scope reported here would be inaccurate and could impact outcomes for future deployments or assessments. Future assessments that wish to experimentally and/or conclusively investigate network-level performance must utilize specialized equipment and software designed to provide a more consistent data set.

While the data captured for this report is an important indicator of user experience on devices operating across a variety of networks, perceived experience is not necessarily a function of network performance. In the future, demonstration network evaluations should understand the difficulty, if not impossibility, of perfectly teasing apart the influences of the network from the device from the application from the user. These variables all interplay with one another to create the final network experience.

Gathered data regarding device-level access/functionality with commercial carriers reflects a snapshot of the user experience on that network and cannot be generalized to commercial network performance on a larger level.

Key Findings

This assessment documents some of the successes and future challenges to consider surrounding this demonstration network. These findings can help Colorado and other areas to:

- Carefully consider the benefits of future public safety LTE networks
- Get the most information from pilot or other demonstration projects, and
- Evaluate their LTE usage at significant regional events to develop a better baseline of the need for, benefit of, and use of a public safety broadband network.

This assessment revealed several key successes associated with how public safety mobile data devices and applications utilized the BC-14 demonstration network including:

- **The BC-14 demonstration network deployed in support of the 2015 FIS Alpine World Ski Championships demonstrated that private commercial entities possess the technical capabilities necessary to design, implement, test, and operate a public safety-dedicated broadband network.** The industry partners involved in this demonstration successfully deployed a network utilizing BC-14 frequencies that supported non-mission critical communications during a real-world public safety event.
- **This BC-14 demonstration network demonstrated that public safety agencies, when exposed to dedicated broadband network access, desire continued access to that network.** User statements throughout the event, and specifically throughout OEC/ICTAP's evaluation period, emphasized their desire to keep the network operational beyond the end of this specific event. A desire for continued operation is a strong indicator that access to a dedicated public safety broadband network is valuable to response and emergency management personnel.
- **This BC-14 demonstration network demonstrated that public safety can benefit from access to a dedicated public safety broadband network.** Users performed functions, accessed information, and maintained situational awareness in ways that were either not available or not possible with the technologies provided for them on previous events. These functions, information, and awareness capabilities enhanced their ability to maintain the safety and security of the 2015 FIS Alpine World Ski Championships.
- **Devices operating on the BC-14 demonstration network recorded reasonably consistent and usable downlink, uplink, and latency rates throughout the evaluation period.** From a data rate and a latency standpoint, devices operating on the BC-14 demonstration network recorded consistent levels over the variety of testing locations and times. One of the primary goals of a network dedicated to public safety is to provide consistent performance, especially when commercial networks are congested. This finding was most evident during the concert in Vail Village, when devices operating on commercial network recorded noticeable drops in performance, and devices operating on the BC-14 demonstration network continued to operate at consistent performance levels.
- **Evaluators noted the increased functionality available to public safety personnel via the specific applications running on the BC-14 demonstration network**. Although users could access these functions previously via commercial LTE networks

or, in some cases, LMR data networks, this BC-14 demonstration network simply allowed them to do more things more quickly than they could before.

The assessment also identified opportunities for future improvement, including:

- **While providing this network to public safety professionals throughout the Vail Valley brought definable benefits, the network was not necessary to sustain operations.** In part because of the restrictions placed on the deployment by the FCC STA, public safety agencies did not put mission critical communications across the BC-14 demonstration network. The information they did transmit over the network, therefore, was non-mission critical. Users were able to articulate viable "work-arounds" they would have employed had the network not been operational.
- **The BC-14 demonstration network, as deployed in support of the 2015 FIS Alpine World Ski Championships, is a unique but potentially repeatable model for other communities, depending on the resources available.** First, the public/private partnerships required to bring this network to reality are not commonplace nationwide. Colorado is to be commended for building long term relationships with their vendor community and leveraging those relationships to the collective benefit of all involved. Communities who have not cultivated such relationships generally would not have the technical expertise or the equipment on hand to replicate the network constructed in the Vail Valley. Second, the estimated cost to build this network (achieved via donated equipment and labor from industry partners) exceeds the budgetary capabilities of most events. Although the resources to execute this type of demonstration network are significant, the benefits are also significant. This type of network allows a community to perform testing, to assess plans, policies, and procedures, and, perhaps most importantly, to put devices into the hands of users and make a future capability real and tangible to that user.
- **This BC-14 demonstration network was a temporary network erected specifically to support a time-limited event.** While the network leveraged some permanent infrastructure assets, it heavily relied upon deployable temporary assets as well. As OEC/ICTAP Evaluators, event planners, and communication technicians all noted, relying on temporary deployable equipment presents significant challenges for both short term and long term operations.
- **Future networks require significant policy and procedure enhancements, as well as hands-on user training opportunities, to provide the most benefit to the public safety community.** The thrust of this project was to provide a demonstration of the network's capability. If dedicated public safety broadband access is to become an operational reality for the nation, agencies must begin to tackle significant policy and procedure gaps. They must also plan for, develop, deploy, and evaluate the training programs needed to accompany the emerging public safety technologies that utilize this type of network.

Conclusion

The BC-14 demonstration network fielded in support of the 2015 FIS Alpine World Ski Championships was a successful and remarkable example of the power of public/private partnerships to produce a definable benefit for the public safety community. The State of Colorado, Town of Vail, Eagle County, and all of their public safety and vendor partners conceived of, designed, implemented, and utilized a public safety-dedicated LTE network that improved user access to broadband data services throughout the event.

In total, the successes of the network, even when tempered by the noted areas for future improvement, demonstrate the value of providing responders with access to a ubiquitous, permanent, nationwide public safety broadband network. The true benefit of this type of demonstration network came from its ability to:

- Provide users with the opportunity to experience the benefits of the network firsthand.
- Provide administrators with the opportunity to make tangible what once was theoretical, engaging executives in lasting discussions on the need to support and prioritize public safety broadband efforts.
- Provide researchers with the opportunity to learn from deployment decisions and operational requirements in order to further improve user access to this dedicated spectrum in the future.

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1 INTRODUCTION

The Department of Homeland Security (DHS), Office of Emergency Communications (OEC) supports and promotes the ability of emergency responders and government officials to communicate in the event of natural disasters, acts of terrorism, or other human-caused disasters, and works to ensure, accelerate, and attain interoperable and operable emergency communications nationwide. The Interoperable Communications Technical Assistance Program (ICTAP) provides technical assistance to states and urban areas for voice and data public safety communication projects. OEC/ICTAP works with local, state, and federal interoperability efforts to enhance agencies' and individuals' overall capacity to communicate with one another. More information about OEC/ICTAP and other OEC work products related to interoperable communications can be found at www.publicsafetytools.info.

The State of Colorado Statewide Interoperability Coordinator (SWIC) requested OEC/ICTAP assistance with evaluating public safety mobile data devices and applications utilizing a temporary band class 14 (BC-14) Long Term Evolution (LTE) public safety broadband demonstration network at the 2015 Fédération Internationale de Ski (FIS) Alpine World Ski Championships in Vail and Beaver Creek, Colorado (hereafter referred to as the BC-14 demonstration network). This report is a detailed accounting of that evaluation and includes findings, recommendations, and next steps.

1.1 Background

The BC-14 demonstration network is the culmination of several years of combined efforts across multiple layers of government and private industry. Below is a brief background review on the steps taken to bring this network to fruition.

1.1.1 2015 FIS Alpine World Ski Championships

In 2010, the FIS announced that the 2015 Alpine World Ski Championships would return to the Vail Valley for the first time in 16 years. The World Championships "represent the largest and most impressive collection of ski racing talent in the world, second only to the Olympics."[1] These Championship ski races took place from February 2 to 15, 2015 at venues at both the Vail and Beaver Creek ski resorts, drawing over 800 international athletes and staff from 70 nations, 2,000 press members, and upwards of 150,000 spectators to the rugged, mountainous area. The events were televised to an estimated 750 million viewers worldwide.

The Vail Valley is in Eagle County, located in the alpine terrain of Central Colorado along the I-70 transportation corridor. The county includes both ski resorts (Vail and Beaver Creek) utilized for this event. The Valley's average elevation is 8,150' above sea level and is largely surrounded by the White River National Forest. Vail Mountain itself summits at 11,570'. Eagle County encompasses approximately 1,692 square miles and includes about 52,197 residents[2].

[1] http://www.vvf.org/athletics/2015-world-championships
[2] 2010 US Census

This international event, therefore, easily added triple the daily number of persons present in the Valley. The area is easily accessible from I-70 but presents extremely difficult topography from a radio frequency (RF) propagation perspective.

1.1.2 NTIA Broadband Infrastructure Project (BTOP) Award

In 2010, Adams County, Colorado and its Communications Center (ADCOM911) received a $12M Broadband Technology Opportunities Program (BTOP) grant award from the US Department of Commerce, National Telecommunications & Information Administration (NTIA) to develop and deploy a 700 MHz interoperable wireless broadband network for use by approximately 2,000 first responders from agencies operating within Adams County and the Denver International Airport[3]. With the passing of the Middle Class Tax Relief and Job Creation Act of 2012, NTIA partially suspended BTOP grants to give the federal government and Adams County time to ensure that “equipment and facilities bought with taxpayer funds will be incorporated into the new national public safety broadband network.”[4] Congress assigned the deployment, maintenance, and operation of this national public safety broadband network to the First Responder Network Authority (FirstNet) within NTIA that same year.

During 2012 and 2013, Adams County continued to develop links and elements of their backhaul network while the partial suspension remained in effect. This partial suspension was lifted by NTIA in the first quarter of 2014, which allowed Adams County to resume development of its grant funded broadband network. Adams County activated six sites on the system in the second quarter of 2014[5] and completed the remainder of the project’s 16 sites by the fourth quarter of 2014[6].

The Spectrum Manager Lease Agreement (SMLA) between FirstNet and ADCOM911 did not allow the State of Colorado to operate the network beyond Adams County’s borders, thus precluding any connection between the BC-14 demonstration network and the ADCOM911 BTOP Core. However, the public/private relationships formed through this BTOP project served as the foundation for the vendor community relationships that Colorado leveraged to establish the BC-14 demonstration network (see section 1.1.4 below).

1.1.3 Governor’s Office of Information Technology FirstNet Colorado

In 2014, the Governor of the State of Colorado, through the Office of Information Technology (OIT), established FirstNet Colorado (FNC) to “lead the state’s efforts to plan, develop, and support deployment of the National Public Safety Broadband Network (NPSBN) in partnership with FirstNet.”[7] FNC continues to engage in outreach efforts with stakeholders across the state of Colorado as well as spearheading consultation efforts with FirstNet. The designated State Point of Contact (SPOC) for FirstNet is an employee of OIT.

[3] http://www2.ntia.doc.gov/colorado
[4] http://www2.ntia.doc.gov/files/grantees/20120511095538760.pdf
[5] http://www2.ntia.doc.gov/files/grantees/nt10bix5570157_adams_county_communications_center_inc_ppr2014_q2.pdf
[6] http://www2.ntia.doc.gov/files/grantees/nt10bix5570157_adams_county_communications_center_inc_ppr2014_q4.pdf
[7] http://www.oit.state.co.us/strategy/firstnet

1.1.4 Public Safety LTE Demonstration Network

The BC-14 demonstration network for the 2015 FIS Alpine World Ski Championships began as a collaborative discussion among the Vail Police Department Chief (acting on behalf of public safety agencies across Eagle County), the State of Colorado SPOC, and select public safety communication vendors over a year and a half before the event. Because Colorado was a BTOP grant recipient, discussions began in earnest with the vendor community, and specifically General Dynamics Mission Systems® (GD-MS), supporting that grant project. There were initial discussions to connect a remote network in Vail back to the ADCOM911 Core, but this approach was not permissible under the conditions of the ADCOM911 SMLA. GD-MS had already placed a Cell on Wheels (COW) device in the State of Colorado to support pre-planned events (specifically the annual Phish concert) and knew the value of demonstrating the network to the user community. The Vail BC-14 demonstration network team, therefore, opted to utilize the GD-MS COW as a virtual core and Radio Access Network (RAN) in Beaver Creek to network that core to another core in Vail.

Concurrently, Crown Castle® International Corporation had partnered with the Town of Vail to install a Distributed Antenna System (DAS) in advance of the championships specifically to enhance commercial broadband communications access for event participants. The DAS antennas capable of supporting BC-14 were installed and, thanks to their strong professional relationships with the Town of Vail and public safety agencies across Eagle County, Crown Castle was willing to donate the equipment and services needed to utilize those antennas on a demonstration network dedicated to public safety.

These pieces successfully blended the public/private partnerships formed among GD-MS and BTOP agencies with the public/private partnerships formed among Crown Castle and Vail Valley agencies. GD-MS further leveraged their vendor community network connections to bring Sonim, Drakontas, and SLA Corp into the project. The result was an event-specific private/public consortium of agencies, organizations, and companies dedicated to bringing a BC-14 demonstration network to fruition for the event.

1.1.4.1 Spectrum Access

This BC-14 demonstration network operated in the FirstNet-licensed 700 MHz BC-14 spectrum. Using this spectrum ensured that access to the network was restricted to public safety personnel who were issued dedicated devices capable of accessing that spectrum or who accessed the spectrum on their own devices via a dedicated Wi-Fi hotspot. The network would therefore be dedicated to public safety and not available for use by the tens of thousands of spectators attending the event.

To utilize this spectrum for the demonstration, the State of Colorado applied for and received a one-month Special Temporary Authority (STA) from the Federal Communications Commission (FCC) (with concurrence from FirstNet as the BC-14 official licensee) to operate the BC-14 demonstration network from January 17-February 17, 2015. An STA is the “authority granted to a permittee or licensee to permit the operation of a communications facility for a limited period at a specific variance from the terms of the station or service authorization or requirements of the FCC rules applicable to a particular class of station or service."[8] This STA expired after the completion of the 2015 FIS Alpine World Ski Championships.

1.1.4.2 Equipment

Building a viable and usable BC-14 demonstration network required a significant amount of both fixed and mobile equipment. Private industry vendor partners optimized this network for outdoor operations very quickly and had the equipment fully operational just prior to the start of the event. They provided all of the equipment used in this network. Much of the equipment was provided at no cost to the Vail Valley or to the State[9]. Some of the fixed equipment remained on site (though deactivated, per the terms of the STA) in the Vail Valley after the event, and some equipment was returned to the vendors. In total, FNC stated that deployed equipment included:

- Town of Vail
  - A Radio Access Network composed of 4 eNodeBs integrated into 4 of 29 sites within a DAS
    - Utilized 8 sectors (2 per site), each with a 20 Mbps limit
  - An LTE Core on a 50 Mbps Dedicated Internet Access (DIA) circuit
  - 2 Wi-Fi hotspots (at the Solaris venue)
  - 20 ruggedized Sonim user devices
  - 4 HD cameras and a single Megapixel camera (at the Solaris venue)
  - Raven Electronics gateway used to allow Land Mobile Radio (LMR) traffic to pass over the BC-14 demonstration network (as monitored by the event Communications Unit Leader (COML).
- Beaver Creek
  - One deployable COW at the start/finish venue. The COW included:
    - An LTE Virtual Core (on a Comcast® 1 Gbps DIA circuit provisioned to 20 Mbps) networked back to the Town of Vail Virtual Core via a traditional Virtual Private Network (VPN)
    - A RAN utilizing 2 sectors, each with a 20 Mbps limit
  - 2 Wi-Fi Hotspots
  - 20 ruggedized Sonim user devices
  - A single Megapixel camera

1.1.4.3 Mission

As the BC-14 demonstration network was technically evolving and becoming more of a tangible reality for public safety, event planners began discussions of how best to incorporate the

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[8] http://www.fcc.gov/encyclopedia/special-temporary-authority
[9] SPOC estimates of the cost of the installation and operation of this network throughout the event exceeded $250,000 in vendor-donated time/equipment.

network into their operations. Rather than over-reach and try to use the network too broadly, event planning personnel opted to focus user activities on two specific areas of event management: traffic control and crowd management. These choices allowed for a reasonable amount of activity across the network but kept the deployment and application set small and manageable. Event planners therefore made the deliberate choice to opt for a “small win” rather than risk issues trying to “be all things to all people.” From an evaluation perspective, the specific outcome of this choice was a limitation in the user population for the devices. Field users were, by and large, limited to law enforcement personnel as traffic control and crowd management are primarily law enforcement functions.

1.2 Scope

1.2.1 Time

FNC, Vail Valley public safety agencies, and industry partners deployed this BC-14 demonstration network for the entire duration of the 2015 FIS Alpine World Ski Championships (i.e., from February 2-15, 2015). OEC/ICTAP subject matter experts (SMEs) conducted various tests and interviews from February 10-12, 2015. Town of Vail and Eagle County public safety personnel selected this evaluation period to provide OEC/ICTAP Evaluators (hereafter referred to as Evaluators) with access both to large ski event days and to days without scheduled events. This dichotomy allowed us to compare the user experience during low and high usage periods, and also afforded us the chance to talk with users during operational down times.

1.2.2 Networks

As a condition of the STA, public safety personnel transmitted only non-mission critical information across the BC-14 demonstration network. Our assessment, therefore, does not address mission critical communications used in support of the 2015 FIS Alpine World Ski Championships. OEC/ICTAP limited the scope of the assessment to information passed over the LTE network and did not evaluate information passed via LMR[10], landline or satellite phone, or other hardwired data pathways.

1.2.3 Technologies

Evaluators focused their assessment on how well the deployed network supported public safety users during the event. Because BC-14 devices are not currently available to the general user, public safety personnel in the Vail Valley who wished to operate directly on the demonstration network were provided with ruggedized Sonim devices[11]. Evaluators assessed the user experience with these devices (and the two primary applications loaded onto the devices, Drakontas DragonForce and SLA Corporation ESChat) but did not perform an in-depth analysis of the device or the applications themselves.

[10] For one operational period, LMR signals were transmitted across the BC-14 demonstration network via a Raven Electronics® gateway. This operation was monitored by the COML for the event and established largely for demonstration/proof of concept purposes.
[11] FNC provided between 100-200 users access to the networked Wi-Fi hotspots, which they could access with their personal/department provided devices.

1.2.4 Personnel

Due to operational requirements, shift work, and staff assignments, Evaluators were able to interview a variety of public safety personnel who used devices and applications on the BC-14 demonstration network to one extent or another throughout the event, but were not able to interview all personnel or representatives from all involved agencies. The interviews reported here should therefore be viewed as a sample of the opinions and experiences of users during the event.

1.3 Methodology

Evaluators used several mechanisms to gather the data required for this assessment. We began with a series of teleconferences with FNC staff, Vail Valley public safety personnel, and various industry partners to set expectations for the assessment, to learn how the vendor community was deploying the network, and to understand how the public safety community intended to use the network. During the event, Evaluators relied on two primary data collection approaches, as detailed below.

1.3.1 Technical Data Collection Tools

Assessing true network performance requires extensive tools and equipment, in addition to carefully crafted experimental methodology. For this real-world application, OEC/ICTAP investigated but was unable to procure access to these types of devices due to time and financial constraints. Rather than omit any evaluation of system performance, OEC/ICTAP, in concurrence with FNC personnel, opted to use more simplified commercially available tools to give us a general assessment of how the network functioned in support of the public safety goals for the event.

To this end, OEC/ICTAP focused on evaluating the system at the device, rather than the network, level. Evaluators heavily engaged the Ookla Speedtest®[12] application on personal devices and on the Sonim BC-14 devices to perform frequent network access and speed checks throughout the event. This particular application stores the results of repeated tests and therefore did not require evaluators to physically document the results of each use.

In addition to the Speedtest data, OEC/ICTAP developed two data collection forms intended to standardize data collection processes during the event across the evaluation team (see 4Appendix B). The first form, a Technical Survey, was designed to repeatedly gather data at various venues, at various times, and using various devices throughout the evaluation period. Evaluators repeated the tests listed on this form using personal devices on commercial carriers and using provided Sonim devices on the demonstration BC-14 network. To complete the required series of tests, Evaluators used a number of different applications selected to demonstrate a broad sample of network capabilities, speeds, and signal strength readings. These applications included:

- SignalCheck (Lite or Pro)
- RTR-NetTest
- Mobile Pulse℠

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[12] www.speedtest.net

- LTE Discovery
- Drakontas DragonForce
- SLA Corp. ESChat
- Skype®
- Google® Earth
- YouTube®
- Streaming Video

Using these applications, Evaluators performed a variety of tests on the included devices and, by extension the networks accessed by those devices, throughout the event. The signal testing applications provided metrics such as upload and download speeds. Other applications were used to approximate user experience with the network. Tasks using these applications included completing push to talk VoIP transmissions, zooming in on a map using Global Positioning System (GPS) locating services, completing a video chat, etc.

1.3.2 Operational/User Experience Data

The second form used by Evaluators focused on the more qualitative aspects of user experience with the BC-14 demonstration network (see Appendix B). Evaluators used this form primarily as a primer, referencing a series of questions as they discussed user experience on the network with various public safety personnel in the field, in the Event Command Post (ECP) and in the Incident Communications Center (ICC). Evaluators deliberately kept interviews with operational staff brief (so as to not interfere with ongoing tasks) and somewhat open-ended. This approach allowed users to articulate their true experience with the network, to expand on specifically salient or important features from their point of view, and to address any concerns that may have fallen outside the parameters of our sample question set. The questions on this form, therefore, served as an excellent starting point for user interviews but were by no means all-inclusive of the discussions had with network users.

1.3.3 Data Compilation/Analysis

Following the event, Evaluators compiled and analyzed all of the technical and operational data collected throughout the event. The results of those analyses are presented in three sub-sections of Section 2 below. The first sub-section reports the technical findings from the Speedtest information and the technical survey information. The second sub-section reports on the user experience and discussions with first responders and command personnel from field-based assignments. The third sub-section reports the user experience and discussions from within the ECP and the ICC.

1.4 Reference Materials

Throughout the development of this assessment, Evaluators reviewed a number of articles and reference documents. These items are listed in Appendix A.

1.5 Demonstration Network Partners

The following public safety agencies, private industry partners, and non-governmental organizations (NGOs) made significant contributions to the design, deployment, and usage of the BC-14 demonstration network:

1.5.1 Public Safety Agencies

- FirstNet Colorado/Governor's Office of Information Technology
- Town of Vail
- Vail Police Department
- Vail Fire Department
- Eagle County
- Eagle County Sheriff's Office
- Special Operations Unit (Eagle County SWAT Team)
- Eagle County Paramedic Services
- Colorado State Patrol

1.5.2 Private Industry Partners

- General Dynamics Mission Systems (GD-MS)
- Crown Castle International Corp.
- Sonim Technologies
- SLA Corp.
- Drakontas
- Colorado Mountain Express

1.5.3 NGO Partners

- Lone Star Security
- Vail Valley Foundation


Public Safety LTE
Demonstration Network
GENERAL DYNAMICS
Mission Systems
PUBLIC SAFETY
FNC
CO
CROWN
CASTLE
MissionCritical
COMMUNICATIONS
sonim
BUILT FOR LIFE
Generous support also provided by Drakontas, ESChat, Mobile Pulse, and Colorado Mountain Express.
Feb. 2015
EAGLE COUNTY
VAIL POLICE DEPARTMENT
TOWN OF VAIL
FIS 2015 Alpine World Ski
Championships

2 FINDINGS

This section details Evaluator data analyses and findings in three distinct categories:

1. Device-level quantitative data collection on BC-14 demonstration network functionality in comparison to equivalent data collection on available commercial networks
2. ECP and ICC interview data and observational findings
3. Field user experience and observational findings

For explanations of statistical terms in this section, please refer to Appendix D.

2.1 Device-Level Quantitative Data Collection

In conjunction with the collection of operational and qualitative data, OEC/ICTAP captured device-level quantitative information that measured user access to the BC-14 demonstration network. Recognizing the limitations noted in section 1.3.1 above, this technical methodology included two distinct methods of capturing data using the provided BC-14 handheld devices, as well as personal handheld devices on commercial carriers for comparison purposes. The methods of data capture were as follows:

1. **The frequent use of the Speedtest application while in range of the BC-14 demonstration network.** This application, installed on all test devices, measured downlink (DL) and uplink (UL) data rates, as well as latency times[13]. It therefore provides a snapshot of DL, UL, and latency measurements on that specific device at that specific time. To take measurements, Evaluators manually initiated the test function in the Speedtest app at a variety of locations within the BC-14 demonstration network's coverage area at various times. The application would store the results of the measurements, as well as the geographic coordinates of testing locations, locally on each device. At the end of the test period (February 12th), OEC/ICTAP consolidated all measurements taken using the application into a spreadsheet.
2. **The completion of technical surveys, performed by OEC/ICTAP at a variety of locations and times throughout the BC-14 demonstration network's coverage area.** The primary goal of the surveys was to capture data using additional applications beyond Speedtest, to execute various data functions a user may require on the various devices and networks, and to subjectively rate the user experience while performing those functions. A blank version of these surveys is presented in 4Appendix B for reference.

Whenever possible, OEC/ICTAP performed the tests using both BC-14 enabled devices and commercial devices at the same locations and times, so that reasonable comparisons could be made between the device/application functionality while utilizing various available networks.

The results of the OEC/ICTAP quantitative data collection efforts are presented in this section, along with descriptions of any discernible trends, patterns, and/or insights visible in that data.

[13] Recognize that all of the measurements captured at the device level and using commercially available applications can fluctuate in response to external variables such as the latency involved with reaching to an external (i.e., non-network) server, potential limitations on backhaul/transport both internal and external to the LTE network, etc. Also, DL and UL speeds and latency within the LTE network can vary depending on type (e.g., non-file transfer applications) and priority of applications (e.g., real-time, latency-sensitive applications) and loading on the network in any given time transmission interval in addition to several other factors.

2.1.1 Assumptions/Artificialities

The data reported in this assessment have limited generalizability in several key areas. Attempting to generalize or utilize the data beyond the scope reported here would be inaccurate and could impact outcomes for future deployments or assessments. Future assessments that wish to experimentally and/or conclusively investigate network-level performance must utilize specialized equipment and software designed to provide a more consistent data set.

While the data captured for this report is an important indicator of user experience on devices operating across a variety of networks, perceived experience is not necessarily a function of network performance. In the future, demonstration network evaluations should understand the difficulty, if not impossibility, of perfectly teasing apart the influences of the network from the device from the application from the user. These variables all interplay with one another to create the final network experience.

Gathered data regarding device-level access/functionality with commercial carriers reflects a snapshot of the user experience on that network and cannot be generalized to commercial network performance on a larger level.

To that end, Evaluators noted the following technical assumptions and artificialities during their assessment:

- As noted in section 1.2.3 above, this data relies on commercially available applications that assess network access/functionality from the user device level. Data provided below therefore speak to the user experience with that network rather than network-level performance.
- No commercial carrier representatives were in attendance at the event to speak to their network's design or capabilities, and were thus not interviewed for this assessment. Furthermore, this data is provided for comparison only and the thrust of the conclusions are aimed at the user experience on the BC-14 demonstration network. Review all data provided for the value of relative comparisons rather than for exact data figures which may not be precisely repeatable in other circumstances.
    - Public safety personnel relayed to Evaluators that commercial cellular network providers provided temporary enhancements to their area coverage/capacity specifically for the duration of this event (i.e., the coverage/capacity measured during the event was not equivalent to the normal coverage/capacity for the area). As examples, users said that multiple carriers upgraded their networks in the Beaver Creek venue by attaching new antennas to a structure close to the grandstands (OEC/ICTAP was able to verify the presence of these antennas but were not able to confirm the extent of the upgrades with the commercial carriers). Data for these enhanced networks, therefore, is statistically limited to the confines of the event and is not generalizable outside of that event.
- The Speedtest application (and all commercially available applications that assess network metrics from the device level) includes a number of limitations that impact the resultant data. Specifically,
    - The Speedtest application selects an "optimal" server to perform its data rate and latency tests. The variety of optimized server locations differed for each device, likely impacting the uniformity of latency times across devices. The largest limitation to using this application, therefore, is its requirement to leverage external servers (i.e., it must access the internet) to provide DL, UL, and latency data.

  - Evaluators assumed that the measurements recorded by the Speedtest app are complete and represent the same results seen during testing (i.e., no issues occurred during logging that altered the actual measurements).
  - If the Speedtest application, for any reason, could not complete its test function, those incomplete results were not catalogued in the application's test history. As a result, the data presented here does not incorporate test failures in the evaluation metrics such as data rates and throughputs. These test failures were catalogued anecdotally by OEC/ICTAP, and are discussed in this report where applicable.
- On any completed technical surveys, responses where no value for the experience rating was provided (i.e., no values between 1 and 5 were circled), a value of 1 is assumed if OEC/ICTAP comments corroborate the existence of problems with the test.
- OEC/ICTAP assumes that user training did not significantly impact how the network itself operated but may have significantly impacted network, device, and/or application usage. Training and user familiarity with devices and applications may manifest in various different ways throughout the data.

2.1.2 Analysis of Speedtest Data

This section presents the results and analysis of the data captured by OEC/ICTAP using the Speedtest app in the BC-14 demonstration network's coverage area. The data is presented in three subsections:

- All measurements captured by OEC/ICTAP during the testing period
- A subset of measurements captured in Beaver Creek during the finishing races of the Ladies' Giant Slalom competition on February 12th, 2015
- A subset of measurements captured in Vail Village during the Phillip Phillips concert on the evening of February 12, 2015

The two events described above represent times where OEC/ICTAP believed high amounts of commercial data usage by spectators could potentially impact wireless networks. In each of the subsections presenting these events' Speedtest measurements, OEC/ICTAP describes any witnessed network traffic-related impacts.

2.1.2.1 Aggregated Measurements (all data points captured)

Figure 1 shows the geographic locations where all Speedtest measurements were captured by OEC/ICTAP during the quantitative testing period.

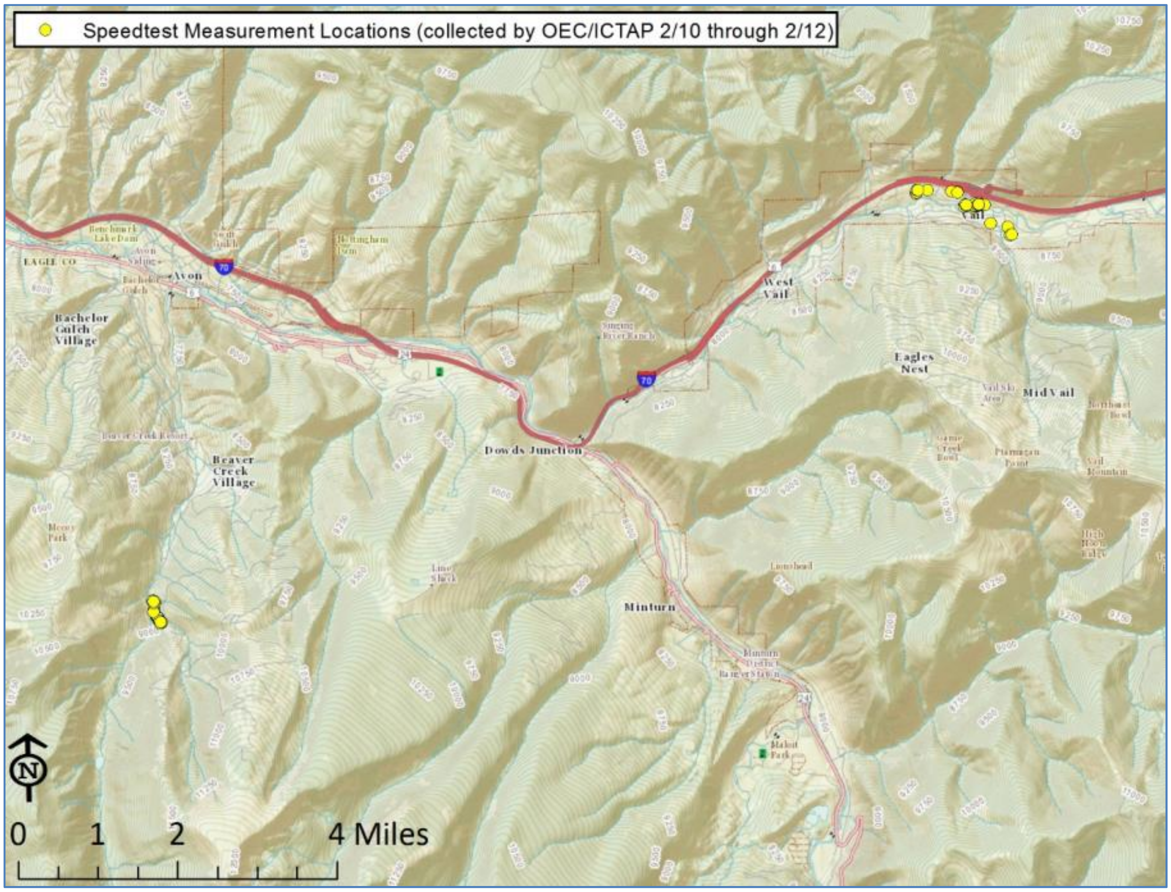

Figure 1: Locations of All Speedtest Measurements

As Figure 1 shows, the measurements were primarily focused on two regions: the town of Vail (specifically near Vail PD and Vail Village) and the Beaver Creek event start/finish line near the deployed BC-14 COW. These regions were the focal point of the testing efforts due to anticipated levels of commercial traffic and also a high concentration of user devices testing the BC-14 demonstration network.

Sample Size

Table 1 presents a breakdown of Speedtest measurements by carrier. OEC/ICTAP Evaluators were each issued a Sonim 7700 handheld device, operating on BC-14, and also used their personal commercial smartphones for taking measurements. As a note, Sonim devices were not enabled to “roam” on to any network (i.e., to commercial networks) besides the BC-14 demonstration network.

Table 1: Breakdown of All Speedtest Measurements

Carrier	Number of Android® Devices Used	Number of iOS® Devices Used	Amount of Speedtest Measurements Taken
Band Class 14	4	0	83
Carrier A	0	1	9
Carrier B	2	0	27
Carrier C	1	0	24

Additional Considerations

It is important to note the following regarding the collection of data using Speedtest:

- Because the thrust of this assessment focused on the device-level user experience with the BC-14 demonstration network, Evaluators ran significantly more Speedtest data on the Sonim devices than on personal devices. As noted above, commercial carrier data is provided for relative comparison only[14].
- Small sample sizes reduce the statistical power to detect significant trends or changes amongst the data. As noted in section 3.3 below, future demonstration network assessments should strive to increase the level of collected data.
- The personal device operating on the Carrier A commercial network used by OEC/ICTAP consistently had technical issues with the Speedtest app, including connectivity problems, GPS-logging errors, and problems with selecting an appropriate server for testing purposes. As a result, some of the Speedtest measurements from this device needed to be removed from the dataset.
- Any of the involved networks may have been "rate limited" (i.e., may have placed internal limits on UL and DL data rates). Rate limitations could have impacted observed results.

Results of Aggregated Speedtest Data

Figures 2, 3, and 4 show the DL data rate, UL data rate, and latency (respectively) for all of the Speedtest measurements, broken out by the network each device accessed.

[14] Commercial networks are designed to different coverage/capacity requirements than the BC-14 demonstration network.

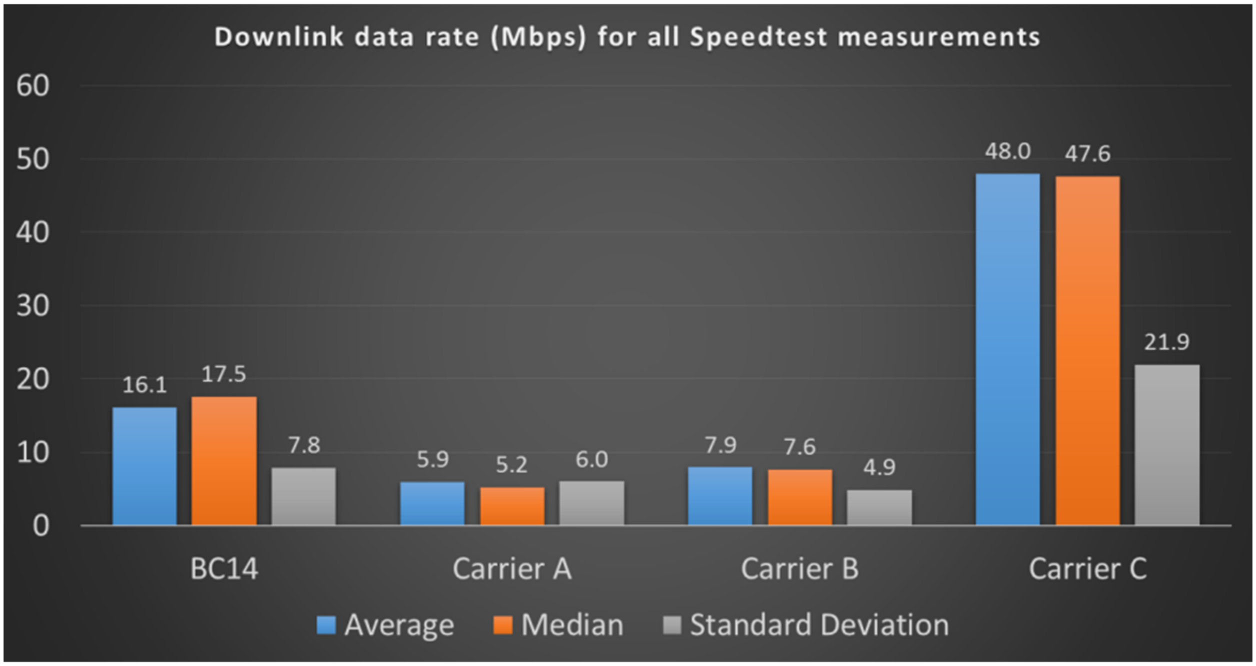

Figure 2: Downlink Data Rate (mbps) of All Speedtest Measurements

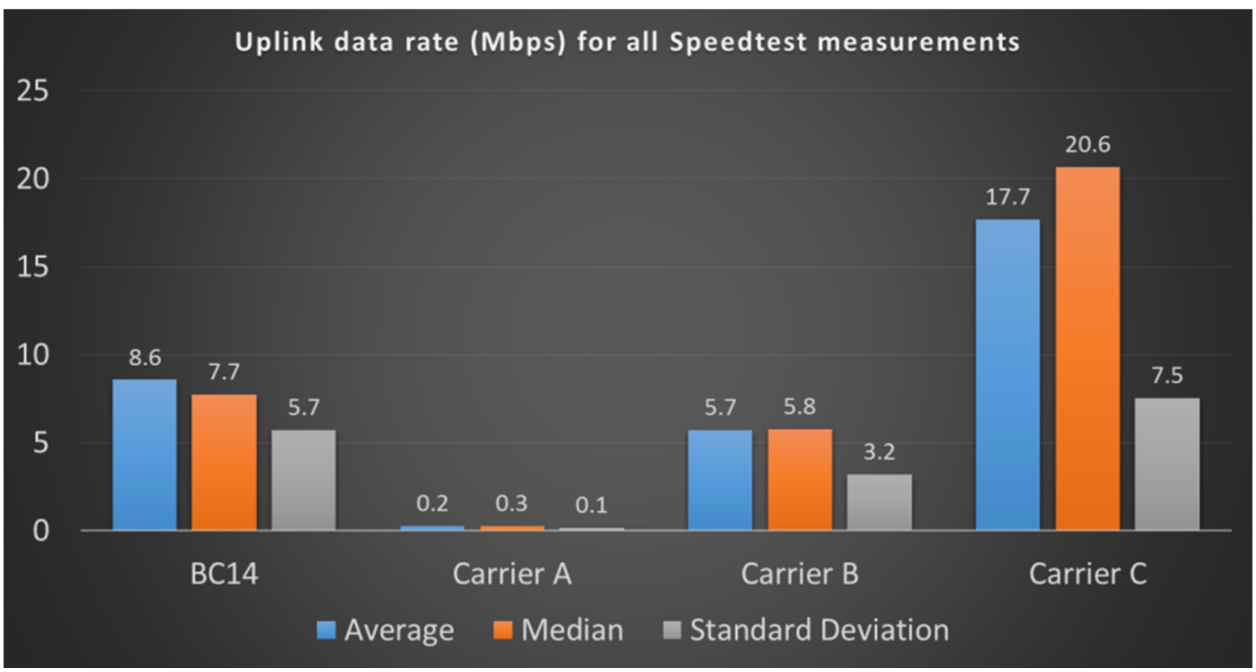

Figure 3: Uplink Data Rate (Mbps) of All Speedtest Measurements

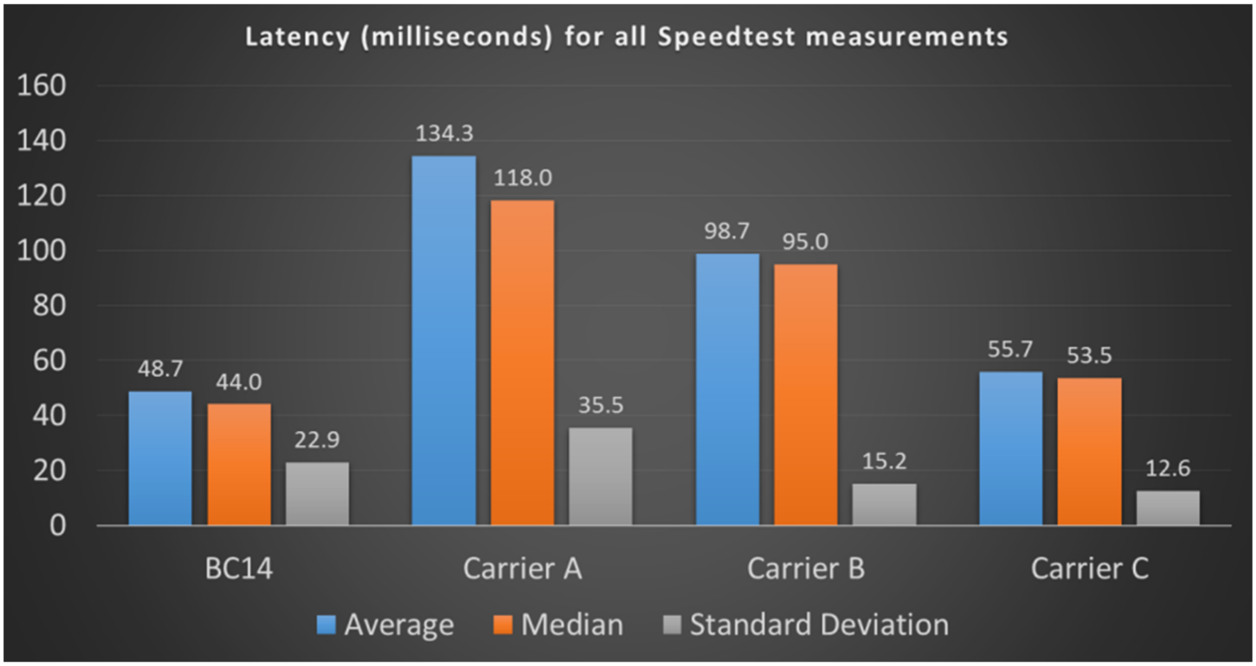

Figure 4: Latency (milliseconds) of All Speedtest Measurements

Analysis

Based on a review of the aggregated Speedtest data, the following occurrences are noteworthy:

- **Devices accessing the BC-14 demonstration network recorded reasonably consistent and functional DL speeds, UL speeds, and latency speeds.** Devices using the BC-14 demonstration network recorded DL, UL, and latency rates that reflect the witnessed consistency and usability of the network. At these levels, public safety users and evaluators did not experience noted delays, degradation, or access issues.
- **The device accessing the Carrier C network recorded the highest DL/UL data rates.** During the testing, OEC/ICTAP noticed that, at some times and locations, the device accessing the Carrier C network reported substantially higher speeds than other devices as reported by the Speedtest application. This result may have been a function of increased network capacity deployed by Carrier C in anticipation of the ski championship events; however, it is difficult to state that correlation for certain without knowledge of Carrier C's actual equipment deployment practices. These high speeds were inconsistent, as is evidenced by the standard deviation reported for the device accessing the Carrier C network when compared to other devices. In addition, these numbers may be skewed by results seen during two specific events: the finishing races for the Ladies' Giant Slalom in Beaver Creek, and the Phillip Phillips concert in Vail. Data specific to each of those events is examined in more detail later in this section.
- **The device accessing the Carrier A network recorded comparatively high latency and low upload rates.** As stated previously, the iOS device used by OEC/ICTAP for collecting results on Carrier A experienced a variety of issues with the Speedtest app. These issues may not reflect the true operation of the network in the Vail Valley area and may have contributed, to a degree, to the recorded values.

It is important to remember, however, that gathered data regarding device-level access/functionality with commercial carriers reflects a snapshot of the user experience on that network and cannot be generalized to commercial network performance on a larger level

2.1.2.2 Data Captured in Beaver Creek during Ladies' Giant Slalom

On February 12, 2015, OEC/ICTAP captured performance data and completed technical surveys during the finishing races of the Ladies' Giant Slalom competition (technical survey results are presented in a later section on this report). The event was expected to attract over 8,000 spectators, and one of OEC/ICTAP's primary goals at this event (in addition to capturing BC-14 performance data) was to evaluate whether commercial networks experienced decreased performance during periods of time when spectator data usage would be high. Specifically, OEC/ICTAP was interested in assessing performance of the commercial networks when popular American athletes (such as former Olympians Lindsey Vonn and Mikaela Shiffrin) completed their ski runs in front of the crowd. OEC/ICTAP anticipated that there would be large amounts of data traffic being exchanged on the commercial networks during these times (e.g., uploading of pictures and video, social media updates, etc.).

Figure 5: View of the Grandstands (from the south) during the Championship Event

At the event, OEC/ICTAP used Speedtest on devices that accessed two commercial networks (Carrier B and Carrier C) and the BC-14 demonstration network. The majority of the measurements were taken near the finish line of the event, either inside or near two VIP tents. These tents were situated approximately 300 feet from the grandstand, where the majority of spectators were congregated. Figure 6 shows the approximate locations of the notable locations at this venue.

Figure 6: Approximate Locations of Notable Places at Championship Venue

The BC-14 service in this area was facilitated through the use of a COW. The COW was erected approximately 1,100 feet from the site of the finish line. The commercial carriers were believed to be operating LTE sites closer to the finish line, where a variety of antennas were mounted on a structure on the east side of the finish line (see Figure 7). However, OEC/ICTAP did not verify the location and/or network capacity used by the commercial carriers with the carriers themselves.

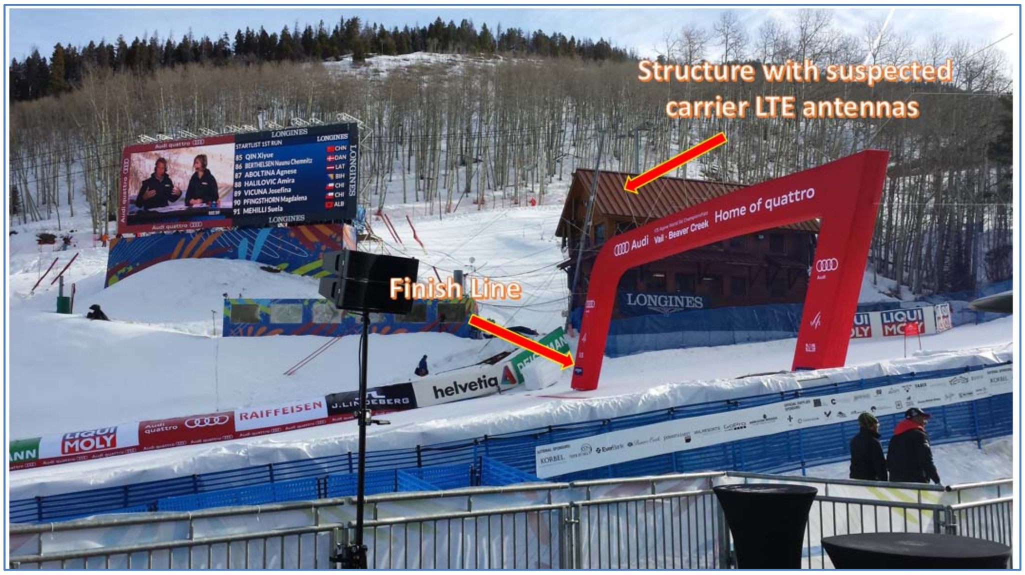

Figure 7: Possible Location of Commercial LTE Antenna(s) near Beaver Creek Finish Line

Figure 8 shows the geographic locations where the Speedtest measurements were captured by OEC/ICTAP during the event on February 12, 2015.

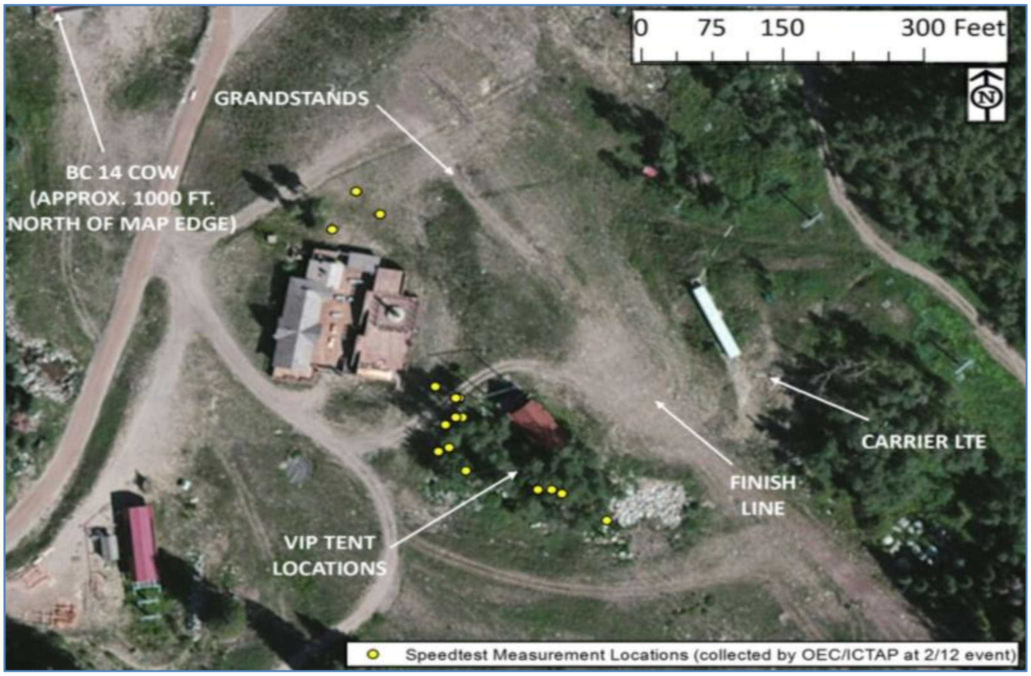

Figure 8: Locations of All Speedtest Measurements Taken during Ladies' Giant Slalom Event

Sample Size

Table 2 presents a breakdown of Speedtest measurements during the ski races event. At this event, two OEC/ICTAP Evaluators were each issued a Sonim 7700 handheld device, operating on the BC-14 demonstration network, and also used their personal commercial smartphones for taking measurements.

Table 2: Breakdown of Speedtest Measurements during Ski Event

Carrier	Number of Android Devices Used	Number of iOS Devices Used	Amount of Speedtest Measurements Taken
Band Class 14	2	0	6
Carrier B	1	0	9
Carrier C	1	0	5

The data points presented in this section are a subset of all collected data points. With many statistical evaluations, as sample sizes decrease, the ability to draw meaningful conclusions from the data can decrease as well. While OEC/ICTAP believes the data captured at this event reasonably portrays the witnessed device-level performance seen by the Evaluators, a larger sample size would be preferable for validating any conclusions.

Whenever possible, the data points captured during this event were taken strategically during times when American athletes completed their ski runs. The goal of this effort was to capture data when the traffic was anticipated to be the highest.

Results of Speedtest Data Collected at the Ski Event

Figures 9, 10, and 11 show the DL data rate, UL data rate, and latency (respectively) for the Speedtest measurements taken during the ski event.

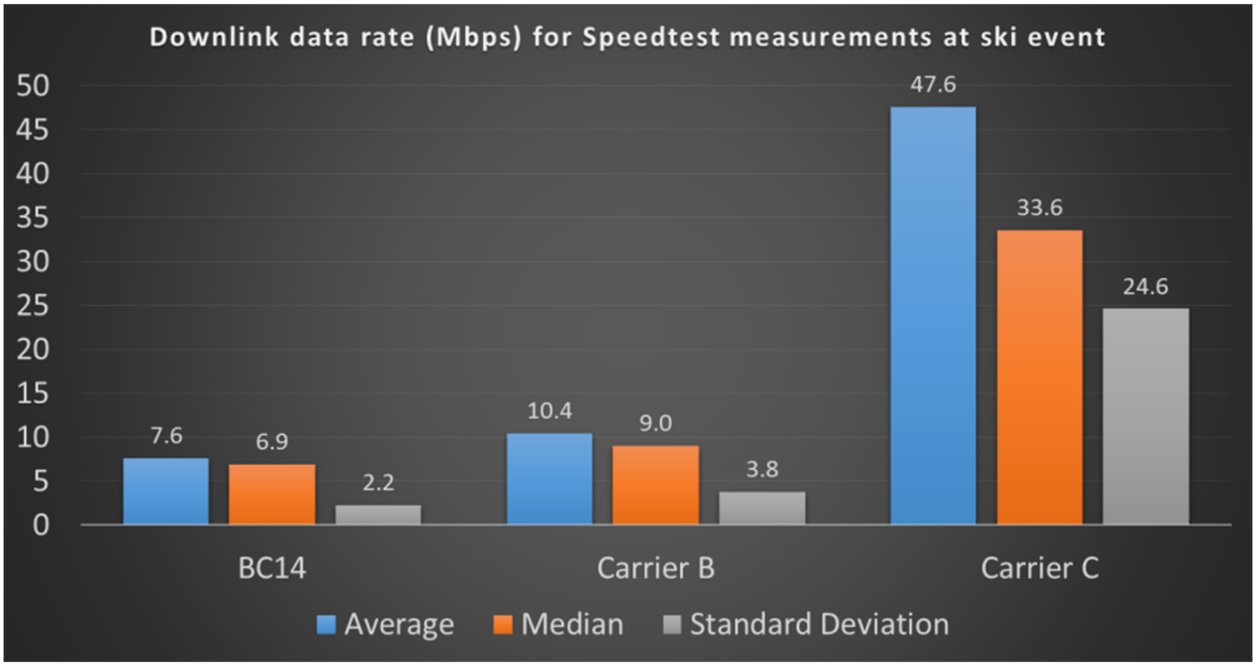

Figure 9: Downlink Data Rate (Mbps) of Speedtest Measurements at Beaver Creek Ski Event

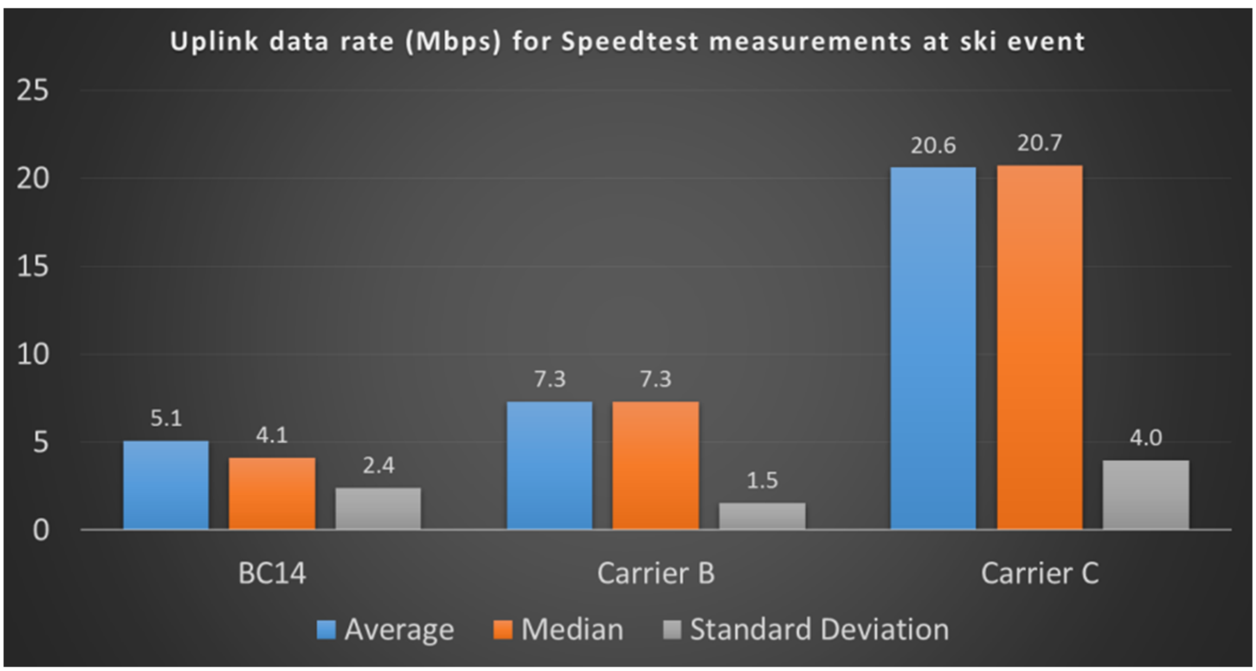

Figure 10: Uplink Data Rate (Mbps) of Speedtest Measurements at Beaver Creek Ski Event

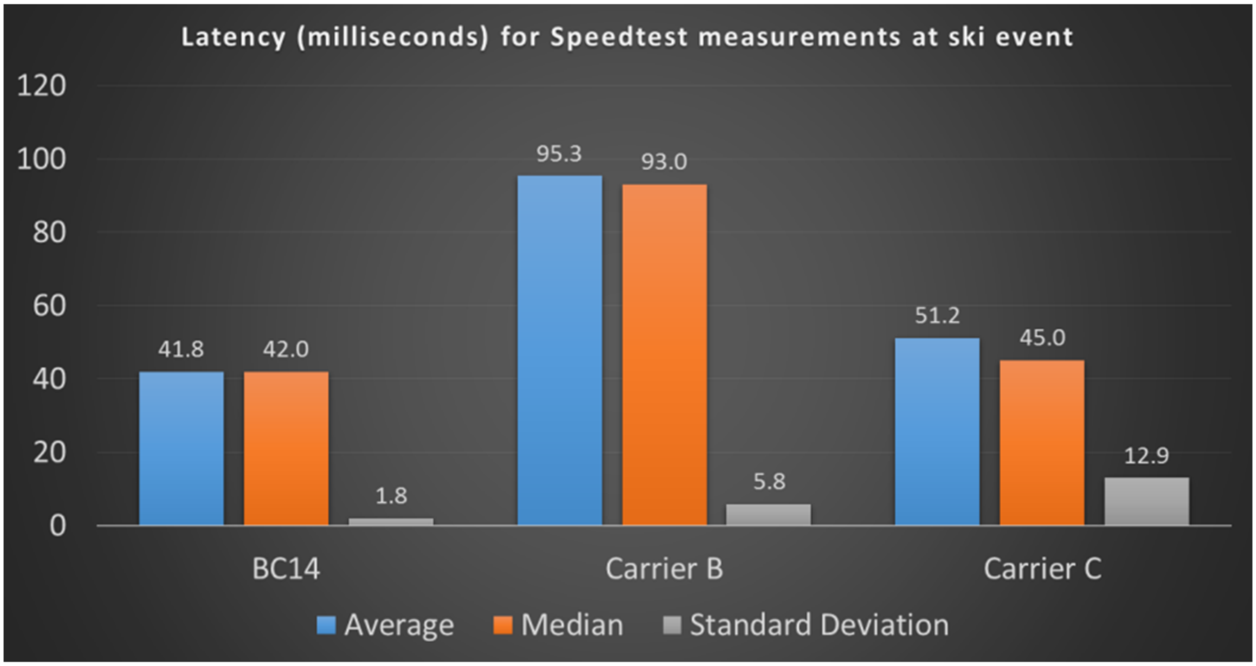

Figure 11: Latency (milliseconds) of Speedtest Measurements at Beaver Creek Ski Event

Analysis

Based on a review of the aggregated Speedtest data, as well as observations made by OEC/ICTAP during the testing, the following occurrences are noteworthy:

- **Devices accessing the BC-14 demonstration network reported consistent and largely adequate DL, UL, and latency rates during the localized event.** As was witnessed when reviewing the aggregated dataset, user devices maintained consistent and adequate access to the BC-14 demonstration network throughout the event. The recorded latency measurements remained low, which may be a function of the relatively low amount of loading on the BC-14 demonstration network. For public safety users, low latency times are crucial for performing mission-critical functions. DL and UL rates were also somewhat lower in this data set than in the aggregate data across the evaluation period. This finding was not entirely surprising, as the BC-14 COW was approximately 1,100 feet from the testing location near the VIP tents and did not have line of sight to the testing devices. Distance to these antennas and obstructions between the antennas and the user devices may impact the DL and UL rates recorded by the devices. Regardless of antenna placement, however, the standard deviations in the BC-14 measurements remained small, indicating consistent DL, UL, and latency values.
- **The closer proximity of the purported carrier LTE sites (when compared to the location of the BC-14 COW) impacted values in the recorded data.** Discrepancies in data rates noted in this data subset are, to an extent, a reflection of where the user device was when it recorded the data relative to the placement of the nearest LTE antennas for that device's carrier. Whereas the commercial carriers' LTE equipment was believed to be on the east side of the finish line (approx. 200 feet from the testing locations with direct line of sight), the BC-14 antennas were 1,100 feet away with no line of sight. During one measurement on the device accessing the Carrier C network, the

DL data rate exceeded 80 Mbps. These levels of throughput are not frequently seen when measuring real-world LTE systems. OEC/ICTAP believes that these results (if they were accurate) were made possible by one or more of the following factors (although none of these were independently verified with Carrier C):
    - Very close proximity to Carrier C's LTE antennas (within 200 feet with direct line of sight)
    - Increased capacity (multiple eNodeBs and additional backhaul) at the event for Carrier C's LTE service
    - Possible use of Carrier Aggregation (CA)
- **Commercial carrier performance did not seem to degrade during anticipated "high usage" moments.** OEC/ICTAP deliberately focused their data collection measurements during the completion of American athletes' ski runs (to best capture potential high traffic scenarios). During these times, no noticeable decrease in throughput or Signal to Interference plus Noise Ratio (SINR) was recorded on devices using either commercial network (using the SignalCheck application). A decrease in this metric would likely cause the user experience with the network to suffer. OEC/ICTAP believes this outcome occurred due to one or more of the following factors:
    - There may have been more than sufficient capacity installed at the site for both commercial carriers to handle any potential congestion.
    - There may not have been as much broadband data usage (i.e., not as many people uploading pictures or videos, etc.) at these events as originally anticipated.

It is important to remember, however, that gathered data regarding device-level access/functionality with commercial carriers reflects a snapshot of the user experience on that network and cannot be generalized to commercial network performance on a larger level

2.1.2.3 Data captured in Vail Village during Concert

On the evening of February 12, 2015, OEC/ICTAP captured data during a Phillip Phillips concert in Vail Village which was attended by an estimated 1,500 spectators. As with the ski championship event in Beaver Creek earlier in the day, one of OEC/ICTAP's primary goals at this event (in addition to capturing data from devices operating on the BC-14 demonstration network) was to evaluate whether devices operating on commercial networks experienced decreased DL, UL, and/or latency values during periods of time when spectator data usage would be high. Specifically, OEC/ICTAP sought to collect data during predicted "high usage" times (i.e., when the performer sang popular songs and immediately after popular songs when the audience might seek to upload pictures/videos taken during those songs).

At the event, OEC/ICTAP used Speedtest to collect data from devices operating on three commercial networks (Carrier A, Carrier B, and Carrier C) and on the BC-14 demonstration network. The concert was an outdoor event that was free for any spectators, and there were no access restrictions. As a result, OEC/ICTAP Evaluators collected data while standing amongst the crowd, in an attempt to approximate both the general population experience with LTE during a congested event and to approximate the public safety user experience when operating within a crowd during a congested event. Evaluators therefore performed tests on personal devices and provided Sonim devices at identical times and identical locations.

Figure 12: View of Crowd in Vail Village Concert (picture taken approx. 100 feet from stage)

The BC-14 service in this area was provided by one of the BC-14 eNodeBs located approximately 750 feet west of the concert venue. The eNodeB was installed at one of the Town of Vail's DAS antenna site locations, and all BC-14 data measured by OEC/ICTAP during this concert at this location was handled by one east-facing sector on this eNodeB. Figure 13 shows an overhead view of the concert venue.

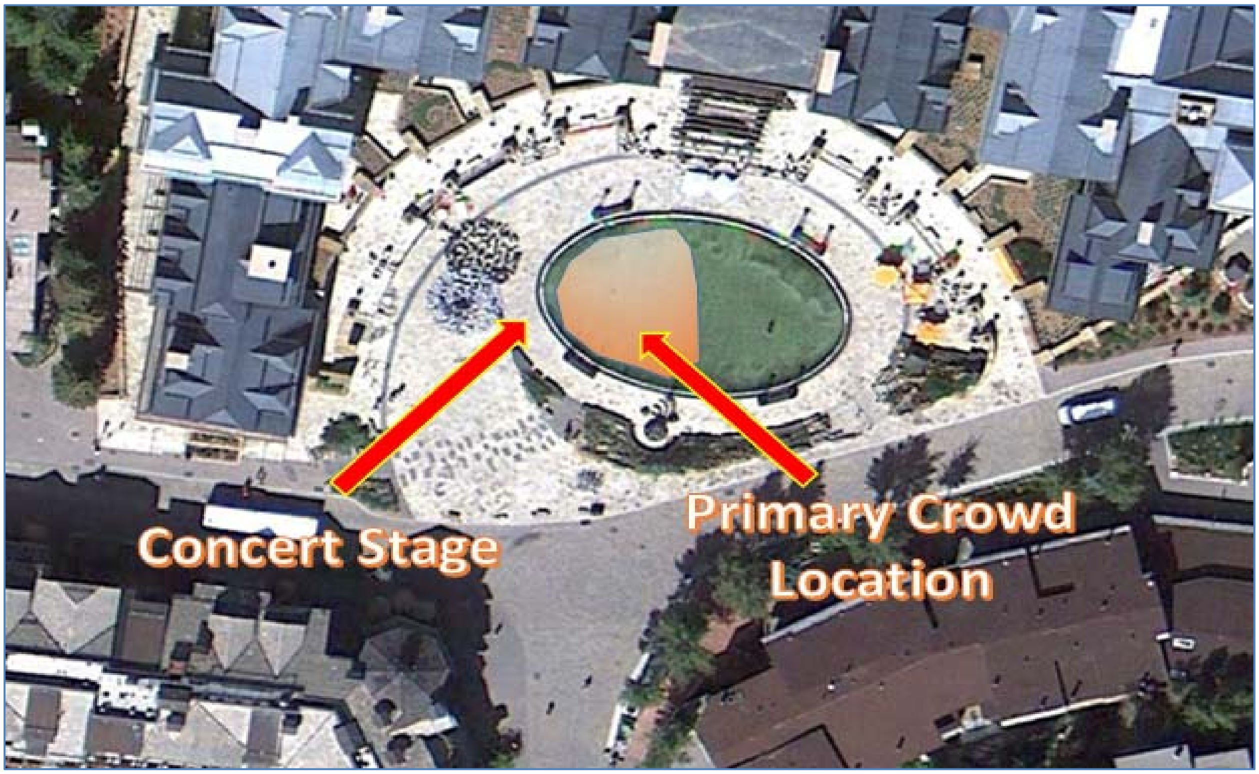

Figure 13: Concert Venue at Solaris in Vail Village

Figure 14 shows the geographic locations where the Speedtest measurements were captured by OEC/ICTAP during the concert.

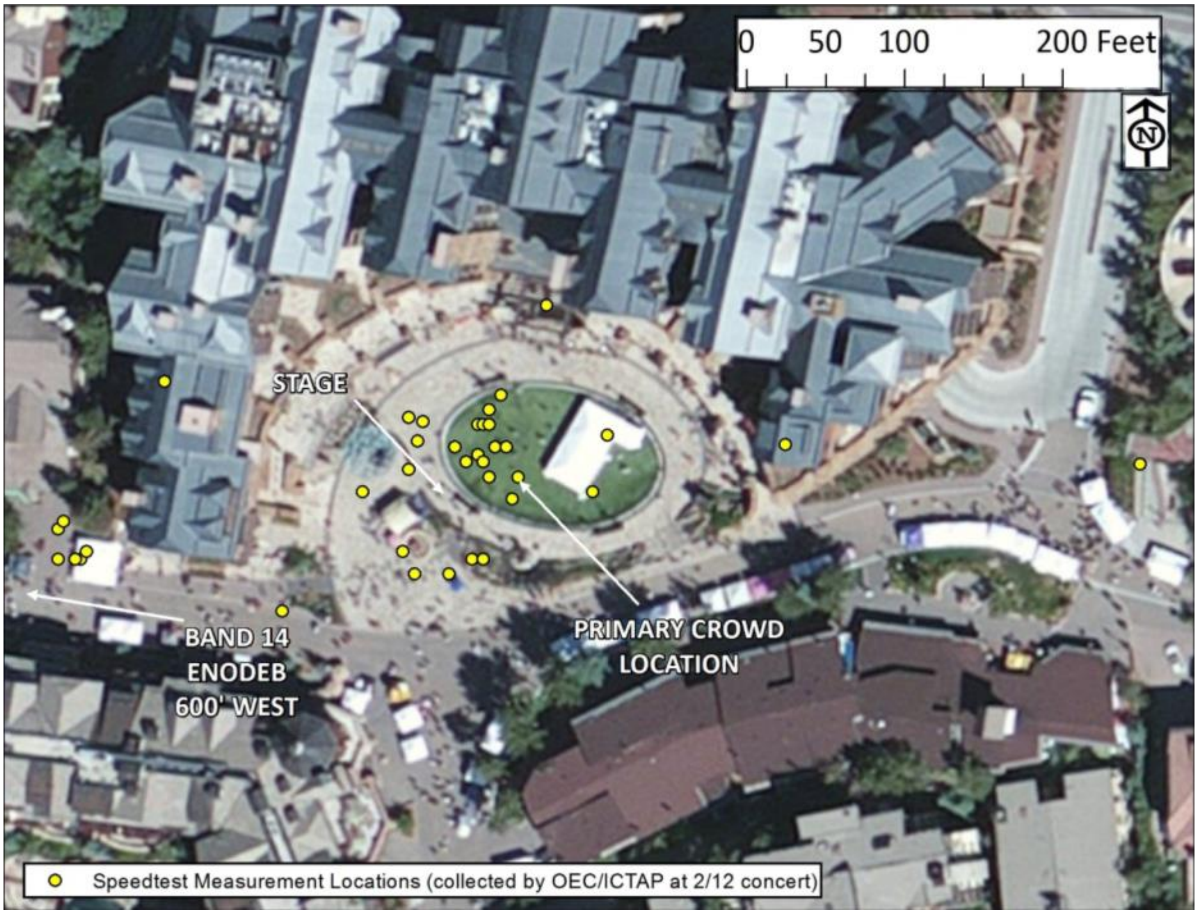

Figure 14: Locations of All Speedtest Measurements Taken during Concert

Sample Size

Table 3 presents a breakdown of Speedtest measurements. At the concert, four OEC/ICTAP Evaluators were each issued a Sonim 7700 handheld device, operating on BC-14, and also used their personal commercial smartphones for taking measurements.

Table 3: Breakdown of Speedtest Measurements during Concert

Carrier	Number of Android Devices Used	Number of iOS Devices Used	Amount of Speedtest Measurements Taken
Band Class 14	4	0	34
Carrier A	0	1	9
Carrier B	2	0	7
Carrier C	1	0	9

Additional Considerations

It is important to note the following regarding the collection of data at the concert:

- All Speedtest measurements presented in this subset of data were collected within the span of one hour.
- Because the thrust of this assessment focused on the device-level user experience with the BC-14 demonstration network, Evaluators ran significantly more Speedtest data on the Sonim devices than on personal devices. As noted above, commercial carrier data is provided for comparison only.
- As noted elsewhere above, sample size impacts the generalizability of data. Future efforts should strive to increase data sets to the maximum extent possible.
- OEC/ICTAP attempted to perform a large amount of Speedtest measurements during two of Phillip Phillips' hit songs, when spectators were using their smartphones for pictures, video, etc. more than during other parts of the concert. The results of these attempts are described in more detail in the Analysis section.
- At times during this specific event (i.e., the concert), devices on various commercial networks were unable to access those networks to perform application testing, to upload content, or to download content. Therefore, unsuccessful Speedtest attempts are not recorded in the app's data logging feature.

Results of Speedtest Data Collected at the Concert

Figures 15, 16, and 17 show the DL data rate, UL data rate, and latency (respectively) for the Speedtest measurements taken during the concert.

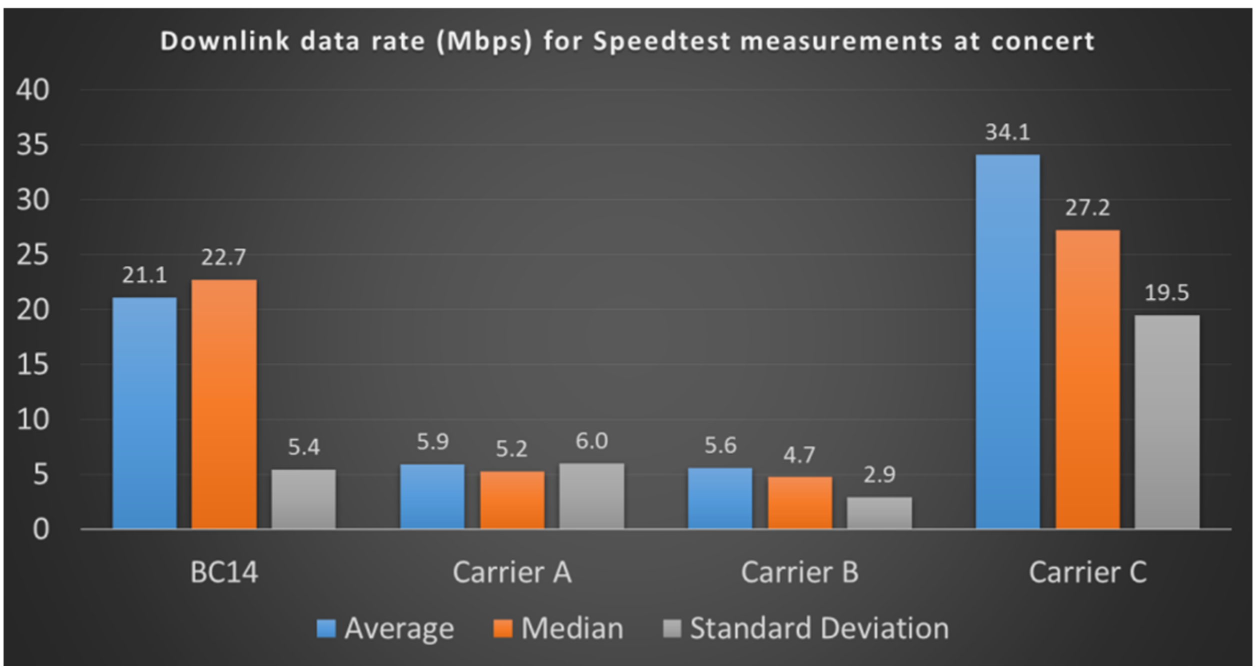

Figure 15: Downlink Data Rate (Mbps) of Speedtest Measurements at Vail Village Concert

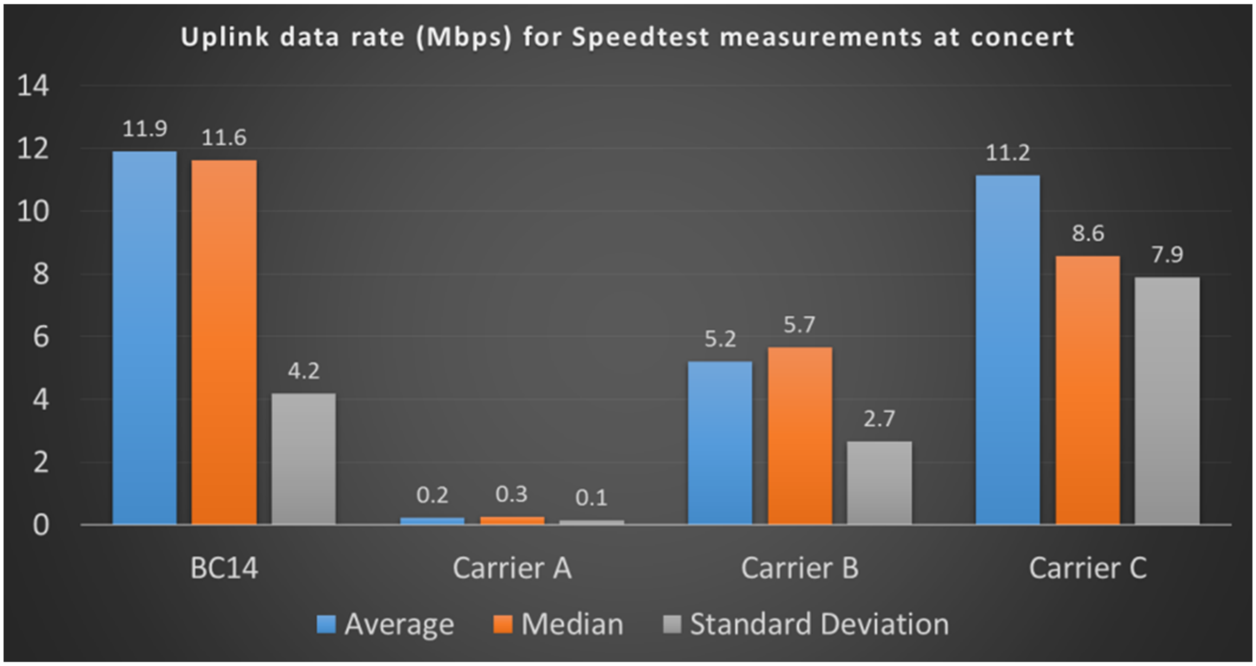

Figure 16: Uplink Data Rate (Mbps) of Speedtest Measurements at Vail Village Concert

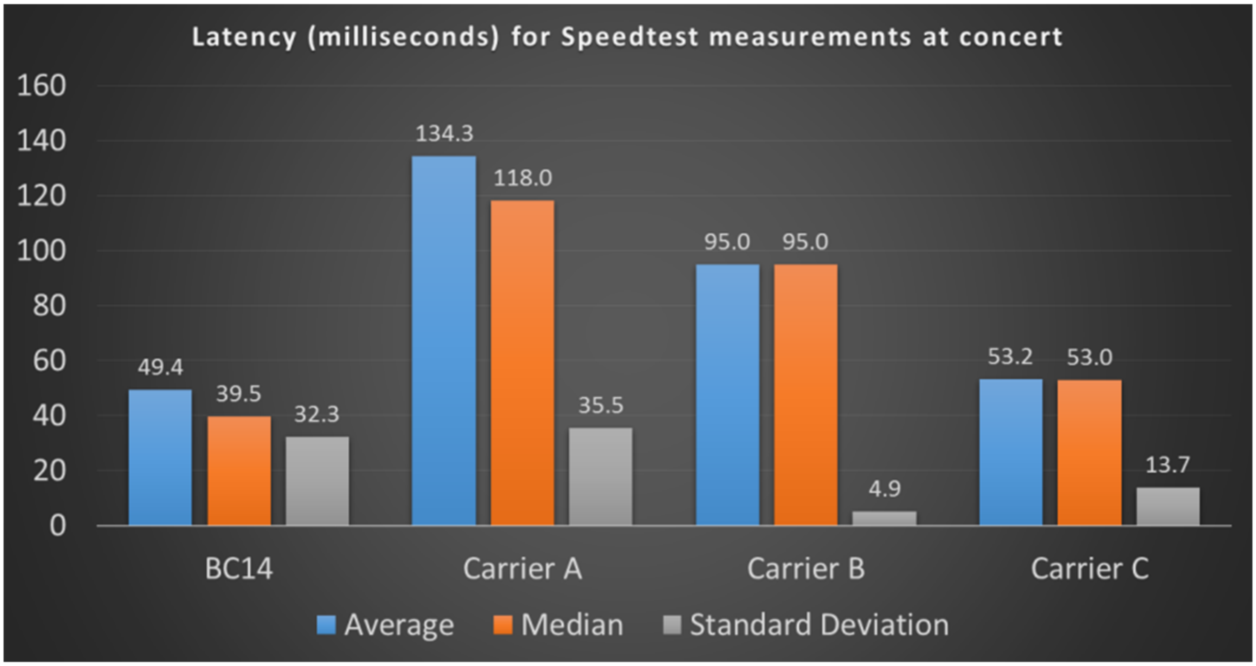

Figure 17: Latency (milliseconds) of Speedtest Measurements at the Vail Village Concert

Results by Time

OEC/ICTAP observed that spectator device usage increased during the latter part of the concert, as the performer played more popular songs. As a result, viewing the captured data over time is useful for analyzing trends. Figures 18, 19, and 20 show the DL data rate, UL data rate, and latency (respectively) in two-minute increments throughout the hour-long duration of the concert.

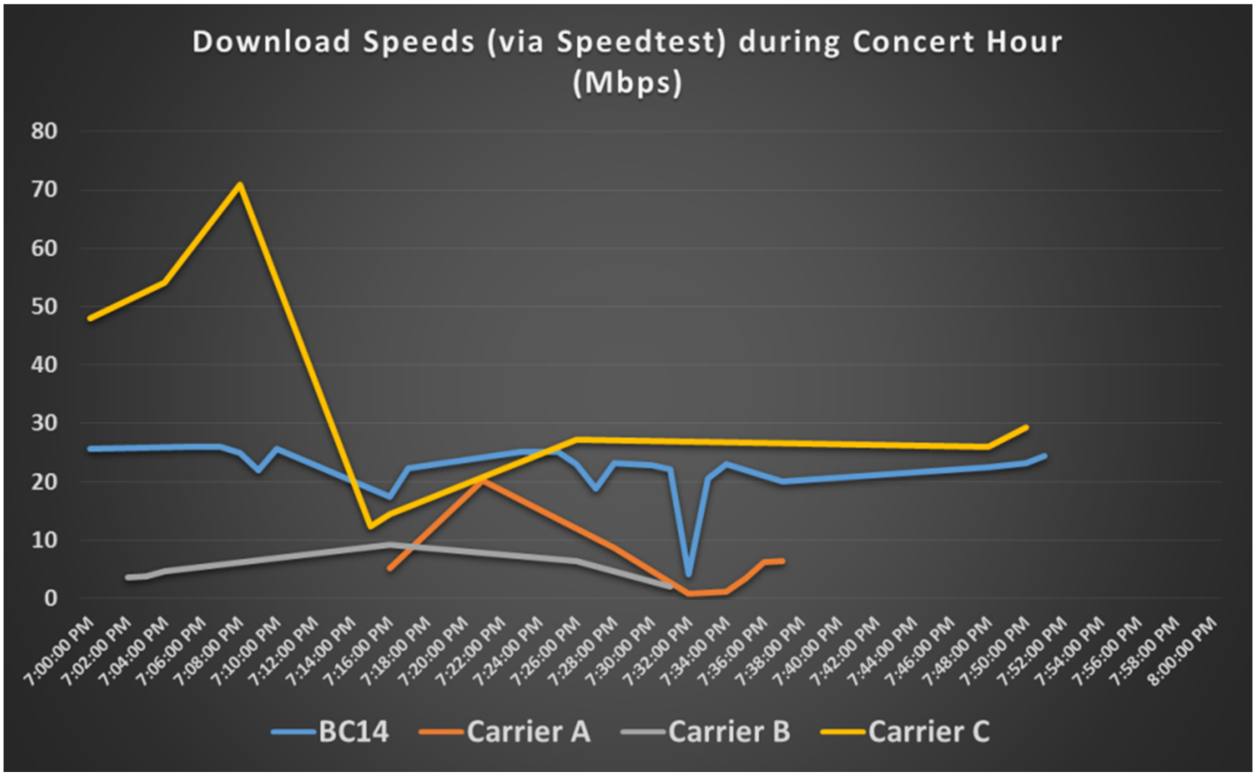

Figure 18: Downlink Data Rate (Mbps) of Speedtest Measurements over Time at Vail Concert

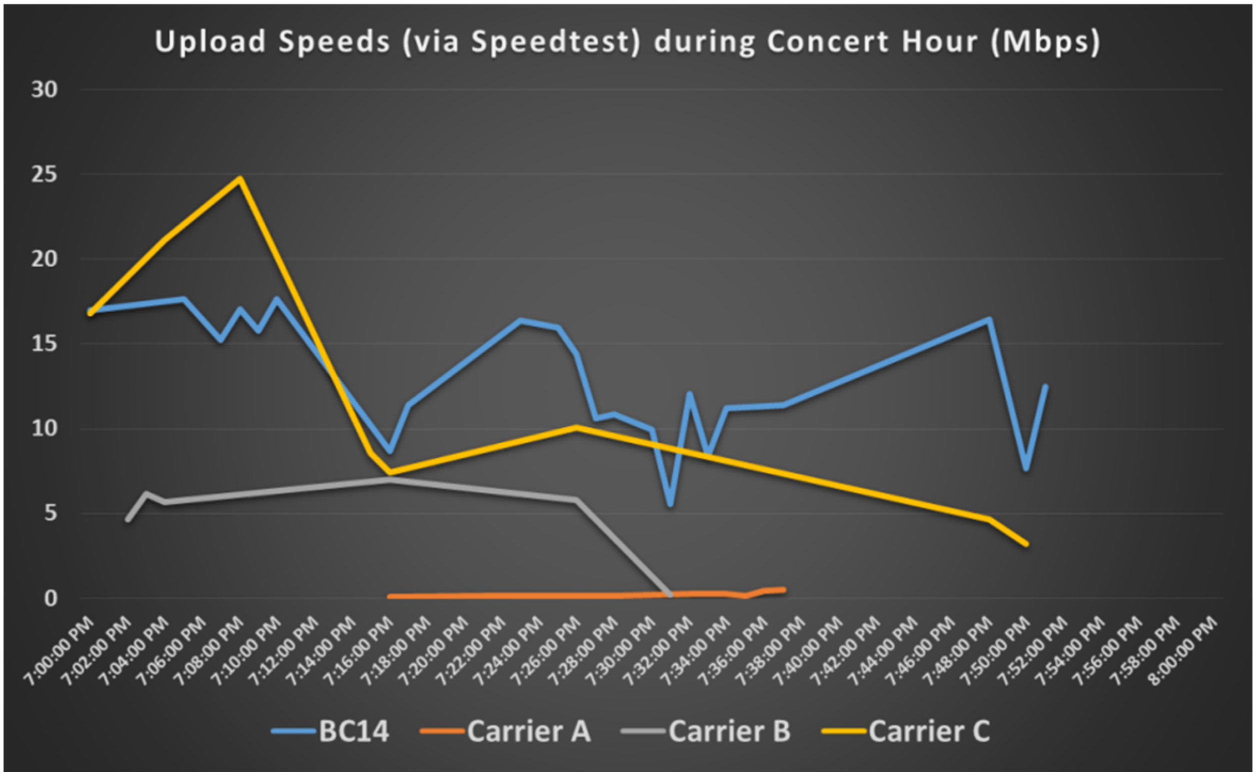

Figure 19: Uplink Data Rate (Mbps) of Speedtest Measurements over Time at Vail Concert

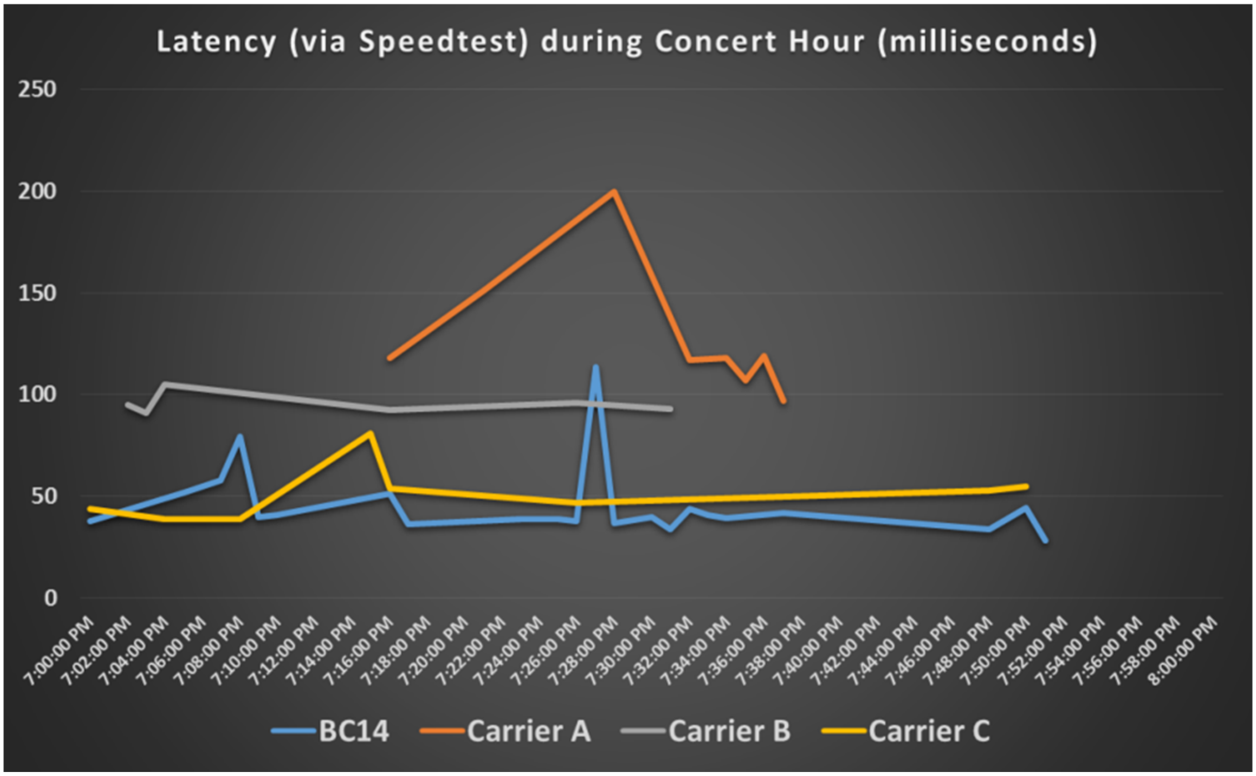

Figure 20: Latency (milliseconds) of Speedtest Measurements over Time at Vail Concert

Analysis

Based on a review of the Speedtest data, as well as observations made by OEC/ICTAP during the concert, the following occurrences are noteworthy:

- **Devices operating on commercial networks experienced degraded functionality, delays, and, at times, a lack of connectivity during the concert**. Reviewing the results shows that recorded throughput data rates, as recorded on devices operating on commercial networks, decreased as the concert progressed. This finding was consistent with the anecdotal experience of OEC/ICTAP Evaluators when using their personal devices operating on a commercial network.
- **Devices operating on commercial networks recorded increased noise levels during the concert that were not replicated on devices operating on the BC-14 demonstration network**. In conjunction with the Speedtest measurements, OEC/ICTAP also monitored other device-level metrics using various applications installed on the devices. During the times of highest commercial traffic during the concert, OEC/ICTAP witnessed decreases in the SINR (using SignalCheck) on the devices operating on commercial networks. These decreases often coincided with the inability to make successful Speedtest connections. No such decrease in SINR was recorded on the devices utilizing the BC-14 demonstration network, and connectivity was consistent.
- **Devices operating on the BC-14 demonstration network recorded UL/DL speed fluctuations, but overall the decreased functionality experienced by devices operating on the commercial networks was not replicated by devices on the BC-14 network.** In addition to this pattern appearing in the data, OEC/ICTAP observed this pattern anecdotally occurring during the concert, as BC-14 devices experienced no connectivity issues, even during the busiest times (popular songs).
- **Devices on specific commercial networks (i.e., Carrier B and Carrier A) experienced a loss of connectivity during the concert.** This finding is indicated by the lack of recorded data for both of those carriers after 7:40 PM. As mentioned previously, unsuccessful Speedtest attempts are not recorded in the application's data logging feature, so they are not reflected in the graphs. However, all OEC/ICTAP Evaluators witnessed the lack of connectivity on devices using these two commercial networks during these times.
- **Devices operating on the BC-14 demonstration recorded consistently low latency rates.** This finding mirrors results collected throughout the evaluation period, indicating that this congested concert event did not impact the devices' access to the BC-14 demonstration network more than other events throughout the evaluation period. Similar caveats to notes mentioned above continue to apply here.
- **The device operating on the Carrier A network suffered from GPS inconsistencies and other technical issues.** Figure 14 shows two data points (yellow circles) that appear to be located to the east of the concert venue. However, OEC/ICTAP did not perform Speedtest measurements in those locations. Both of these data points were logged by the iOS device on the Carrier A network. In addition, the lack of data recorded by the Carrier A device prior to 7:15 PM reflects the connectivity problems the device was having during this time.

It is important to remember, however, that gathered data regarding device-level access/functionality with commercial carriers reflects a snapshot of the user experience on that network and cannot be generalized to commercial network performance on a larger level.

Figure 21 shows a visual representation of the data collected at the concert venue. In the image, upload rates from devices operating on the BC-14 demonstration network are shown as vertical lines that terminate in a cyan icon. The length of these vertical lines corresponds with the measured upload data rate (i.e., the taller the line, the better the upload rate). As the image shows, the upload rate measured on the devices operating on the BC-14 demonstration network taken amongst the crowd at the concert surpassed equivalently collected data from devices operating on the commercial carriers, which are shown with different-colored icons.

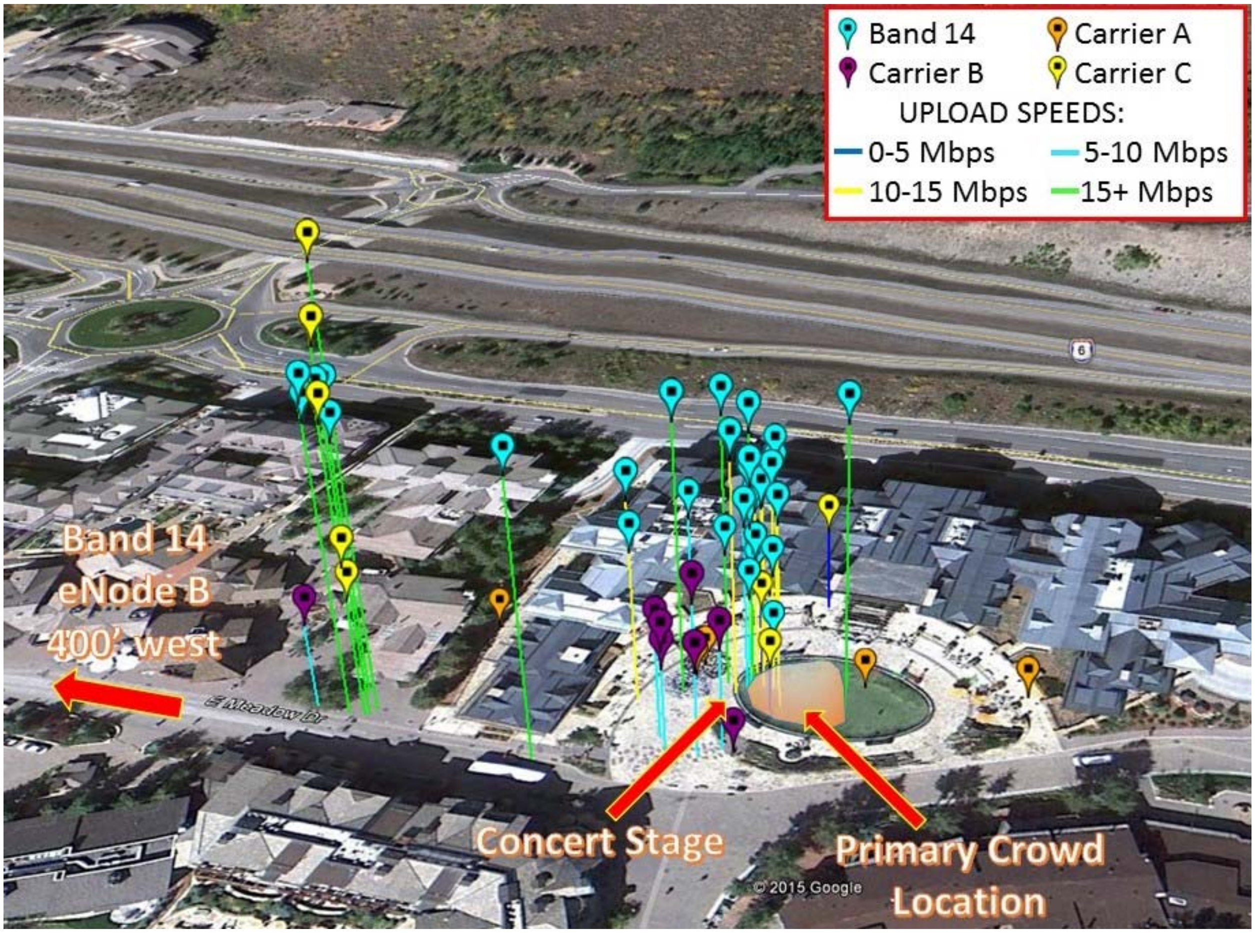

Figure 21: Upload Rates as Measured Using Speedtest (taller lines represent faster data rates)

It should be noted that there are anomalies in the BC-14 demonstration network data that have no explanation from either the context of the data, or the observations of OEC/ICTAP Evaluators. Specifically, the download rate dropped substantially around 7:32 PM, and the latency increased substantially around 7:28 PM. In both cases, the data showed that the data rates recorded on the BC-14 demonstration network devices returned to previous levels after each of these anomalous data spikes.

2.1.3 Technical Surveys

OEC/ICTAP completed technical surveys at multiple locations and times throughout the BC-14 demonstration network's coverage area. OEC/ICTAP used BC-14 handheld Sonim devices as well as personal smartphones to test specific functions using a variety of applications that were installed on all devices (see Table 4), and recorded the results in survey worksheets. A full version of the technical survey is presented in 4Appendix B for reference.

Sample Size

OEC/ICTAP Evaluators completed 28 technical surveys on February 11 and on February 12, 2015. In addition, Evaluators attempted technical surveys during the Phillip Phillips concert in Vail Village on February 12, 2015. However, due to network connectivity issues on devices *not* operating on the BC-14 demonstration network, as well as logistical issues with completing the written surveys amongst the crowd at the concert, the results of those surveys are not included in the data presented in this section. Refer to section 2.1 describing the Speedtest data captured during the concert for more information during that event.

Test Locations

Figure 22 shows the majority of geographic locations where OEC/ICTAP Evaluators completed the technical surveys. In addition to those locations shown in this map, surveys were also completed near the VIP tents in Beaver Creek during the Ladies' Giant Slalom championship runs.

Figure 22: Locations in the Vail Area where OEC/ICTAP Completed Technical Surveys

Table 4: Technical Survey Applications Used and Functions Tested

Application Name	Function	Value Recorded
RTR-Nettest	Use app to perform a test, which measures throughput and other metrics	Successful / Unsuccessful
Speedtest	Use app to perform a test, which measures throughput and latency	Successful / Unsuccessful, DL/UL rate, Latency
SignalCheck	App displays device-level metrics about access to its designated network	Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), Signal to Noise Ratio (SNR), Provider, Physical Cell ID (PCI)
DragonForce	Send a text message to another OEC/ICTAP Evaluator	Rate the overall experience from 1 to 5 (5 being best)
	Add text to the map and have another OEC/ICTAP Evaluator verify it succeeds	Rate the overall experience from 1 to 5 (5 being best)
ESChat	Initiate a Push to Talk (PTT) call with another OEC/ICTAP Evaluator, and test the quality of the two-way communication	Rate the overall experience from 1 to 5 (5 being best)
Skype	Initiate a VoIP call with another OEC/ICTAP Evaluator, and test the audio/video quality of those calls	Rate the overall experience from 1 to 5 (5 being best)
Google Earth	Navigate to an arbitrary point on the globe, and scan the immediate surroundings to gauge the performance of the satellite imagery download	Rate the overall experience from 1 to 5 (5 being best)
YouTube	Watch a video using the service, ensuring a different video for each test (to avoid watching a video cached on the device)	Rate the overall experience from 1 to 5 (5 being best)
Streaming video (no specific app)	Using a browser, navigate to a known live-streamed video service, and view the quality/latency of the stream on the device	Rate the overall experience from 1 to 5 (5 being best)

The following is a list of the general locations where the surveys were completed:

- Inside and outside the ECP (Vail PD Headquarters)
- At the base of the BC-14 eNodeB at Meadow Dr.
- Inside the La Bottega restaurant (kitty-corner to eNodeB on Meadow Dr.)
- Bus stop in Lionshead parking lot
- Near the Solaris concert venue in Vail Village
- During the Phillip Phillips concert in Vail Village (attempted)
- The finish line of the ski races southeast of Vail Village
- The finish line of the ski races in Beaver Creek (not pictured in Figure 22)

Survey Results

Figure 23 shows measured Reference Signal Received Power (RSRP), one of the metrics captured during the completion of the surveys. In LTE systems, the RSRP is somewhat analogous to the control channel in trunked LMR systems: the RSRP facilitates much of the initial set-up for LTE transmissions. Without sufficient RSRP signal, a device cannot communicate with the network. For reference, the closer the RSRP is to zero, the stronger the power received.

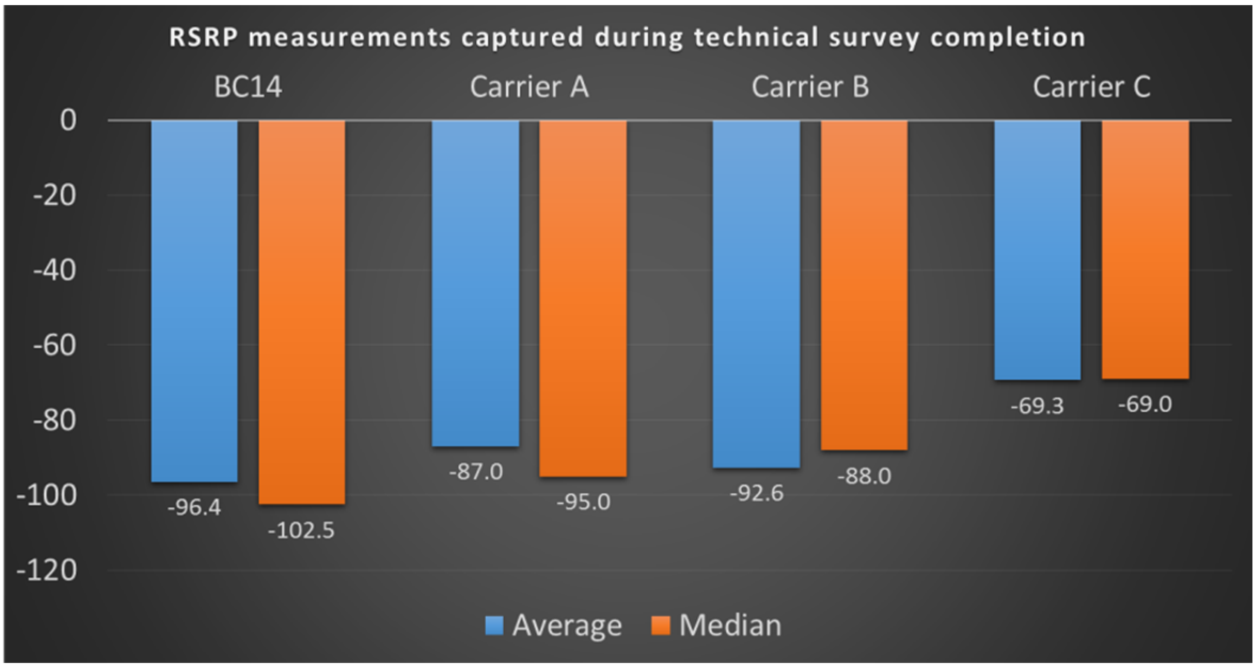

Figure 23: RSRP Measurements

Figure 24 shows the RSRQ (Reference Signal Received Quality) measurements captured during the surveys. RSRQ is an indicator of the quality of the reference signal (RS), and is sometimes considered a more informative indicator of LTE performance than a signal strength measurement. RSRQ also fluctuates as a function of traffic loading. For reference, the closer the RSRQ value is to zero, the higher the quality of the RS.

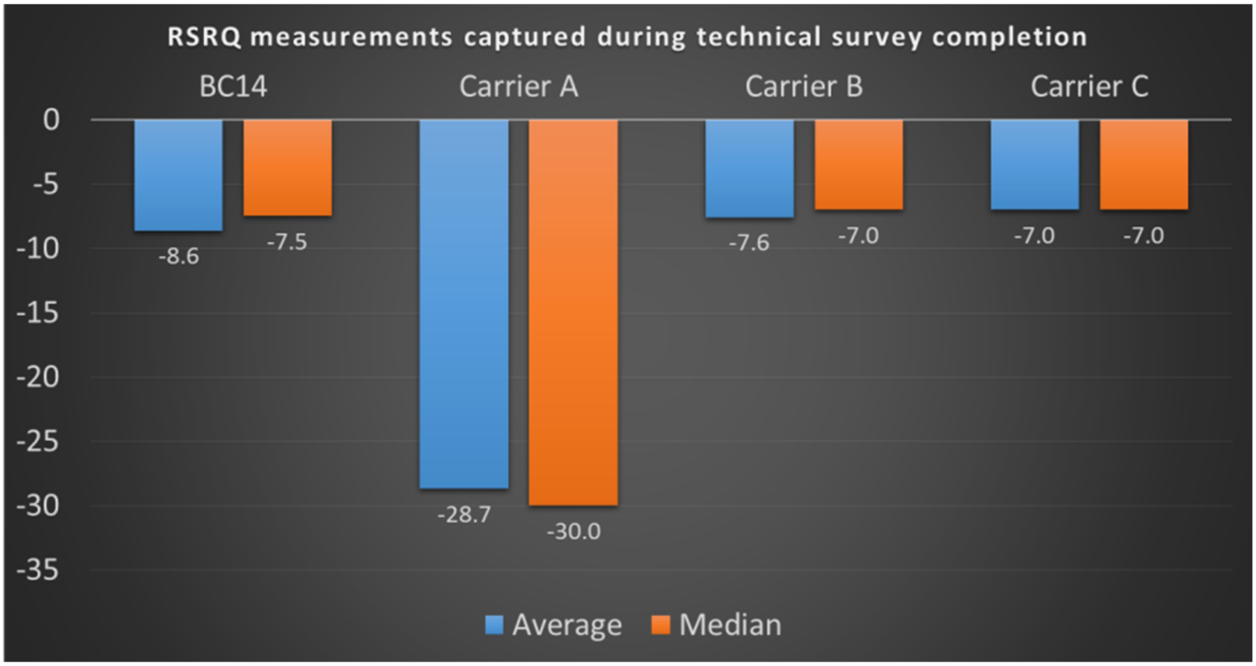

Figure 24: RSRQ Measurements

Figure 25 presents the average rated "experience" for all tested operations performed on the technical surveys. OEC/ICTAP responded with a numerical value of 1 through 5 for each operation performed, with 1 representing a very poor experience, and 5 representing a very good experience. The overall experience values were not based on any measured performance metrics gathered in concert with the surveys but rather were based on the perceived performance, usability, quality, and responsiveness of the application and function being tested.

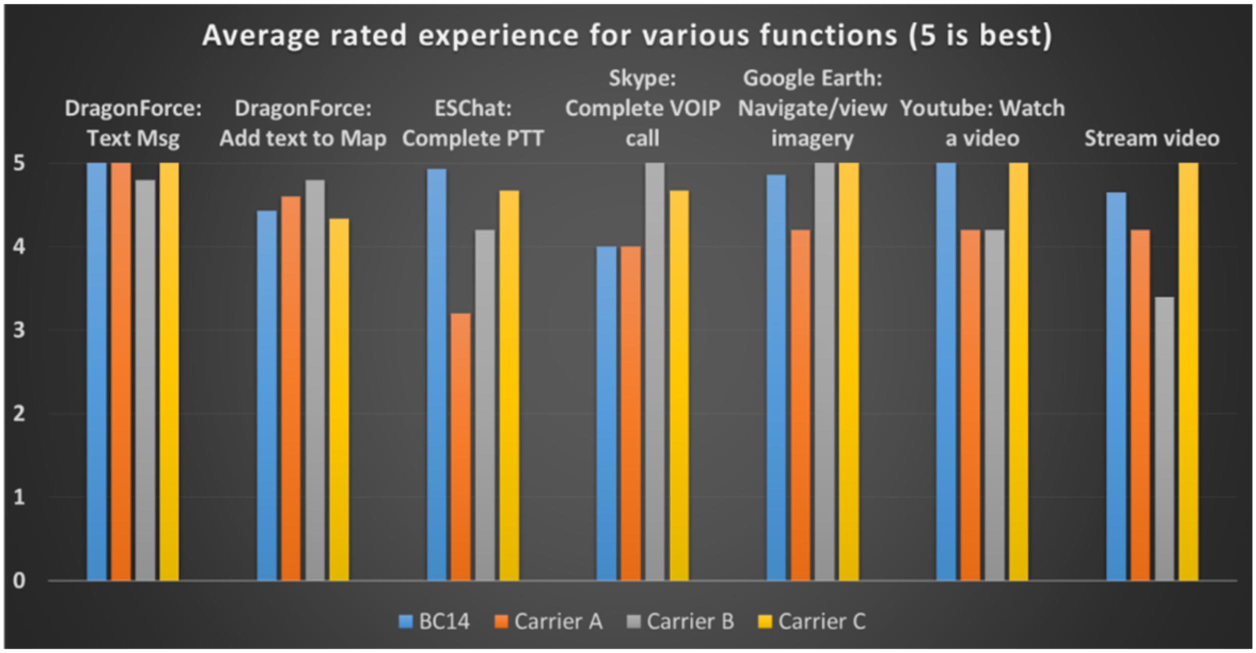

Figure 25: Average Rated Experience for Various Applications and Functions

Figure 26 shows the average experience, by carrier, for all applications and functions tested.

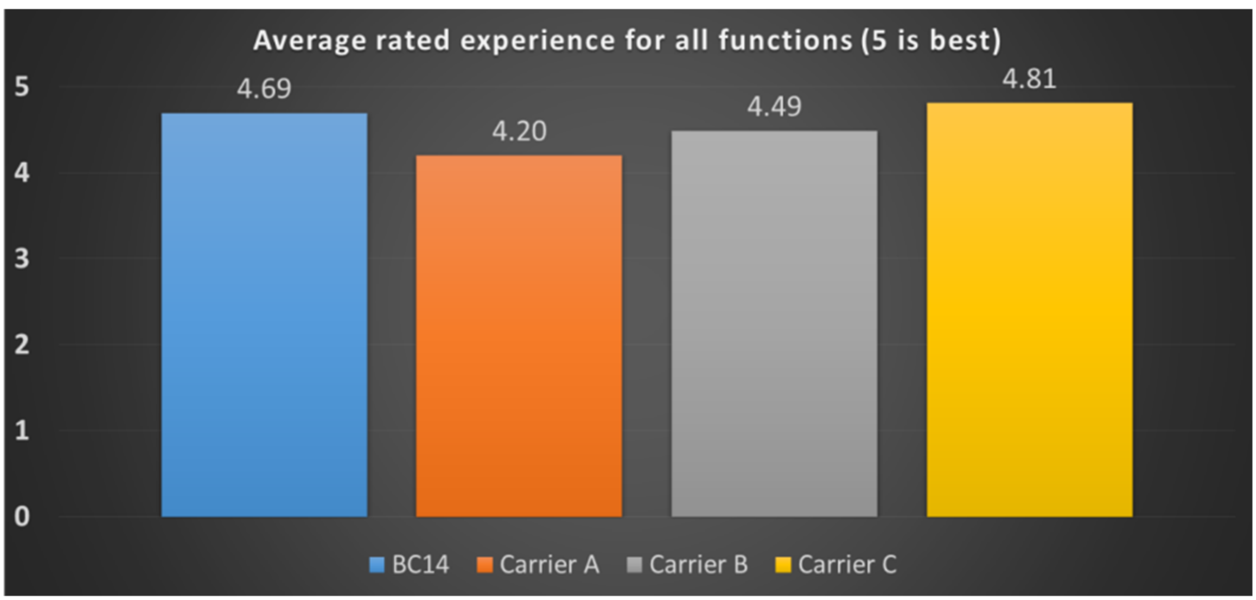

Figure 26: Average Rated Experience for All Applications and Functions

Analysis

Based on a review of the survey results, as well as a review of anecdotal comments made by OEC/ICTAP during the completion of the surveys, the following observations were made:

- **The RSRQ recorded by devices operating on the BC-14 demonstration network was comparable to data recorded by devices operating on the Carrier B and**

Carrier C networks. As noted above, the device operating on the Carrier A network used by OEC/ICTAP was the only device using an iOS version of the SignalCheck application used to perform the measurements. It may be possible that differences between the Android and iOS versions of this application could explain the discrepant values reported above.

- **Recorded RSRP values from devices operating on the BC-14 demonstration network were lower than from devices on other networks. However, these values were still comparable using a relative comparison.** The location of some of the survey testing may have skewed the RSRP data slightly to benefit devices operating on some networks over others. For example, the BC-14 demonstration network was not designed to provide substantial in-building coverage and some surveys were completed indoors. Without a proper comparison of the technical parameters of all systems being measured, it is difficult to say exactly what caused the discrepancy.
- **Overall, application/function experience was good**. The averages of the experience ratings were between 4 and 5 for all devices. Again, however, it is important to note that Evaluators were NOT able to complete surveys during the Phillip Phillips concert, which is when the devices operating on commercial networks reported the most noted degradation.

It is important to remember, however, that gathered data regarding device-level access/functionality with commercial carriers reflects a snapshot of the user experience on that network and cannot be generalized to commercial network performance on a larger level.

2.1.4 Overall Assessment of Technical Data

After analyzing all of the captured quantitative data, the following patterns in the data emerged:

- **Devices operating on the BC-14 demonstration network recorded reasonably consistent and usable DL, UL, and latency rates throughout the evaluation period.** From a data rate and a latency standpoint, devices operating on the BC-14 demonstration network recorded consistent levels over the variety of testing locations and times. One of the primary goals of a network dedicated to public safety is to provide consistent performance, especially when commercial networks are congested. This finding was most evident during the concert in Vail Village, when devices operating on commercial network recorded noticeable drops in performance, and devices operating on the BC-14 demonstration network continued to operate at consistent performance levels.
- **The overall user experience was reasonably good.** Notwithstanding some device, application, and training issues not related to network performance**,** users reported their experience performing functions on a variety of applications very positively. The majority of the issues noted above were not a function of network performance, but rather issues with application inconsistencies, insufficient training/learning time, and non-intuitive interfaces. These issues are likely to differ across any demonstration or permanent network in the future as device and application technology evolves, vendor offerings expand, and training protocols emerge. The high user ratings indicate that a properly-functioning broadband network will enhance, and at the least should not impede, a high-quality user experience.
- **Devices operating on commercial carrier networks may be able to perform well in a congested environment.** The testing performed by OEC/ICTAP at the Beaver Creek

ski championships revealed that device access to and experience with commercial networks can remain good (or at least consistent) during a major planned event. Specifically, reports indicated that commercial carriers had bolstered their network capacity and coverage in preparation for this event. During the Vail Village concert, however, Evaluators were unable to make consistent connections to and/or perform various application functions on devices operating on commercial networks when network usage escalated (i.e., many spectators were using their smartphones to perform data-intensive functions). This drop in performance could be due to insufficient commercial capacity in Vail Village, or perhaps due to a rise in the noise level in certain frequency bands when activity is high. Additional testing of these phenomena may be warranted.

The quantitative data captured by OEC/ICTAP indicated that the experience of operating on the BC-14 demonstration network was largely comparable to the experience of operating on a commercial network[15]. The notable exception to this conclusion appeared during the concert event when the experience of operating on the BC-14 demonstration network demonstrably exceeded the experience of operating on the commercial networks. This demonstration network was therefore capable of providing non-mission critical coverage, capacity, and functionality to public safety users during this event.

2.2 Field User Experience and Observational Findings

Throughout the event assessment, Evaluators interacted directly with public safety personnel who had used devices on the demonstration network. We utilized the information from these interviews, in conjunction with our experiences using the BC-14 demonstration network, to formulate a series of functionality assessments. Our discussions focused on three primary areas, shown in Figure 27.

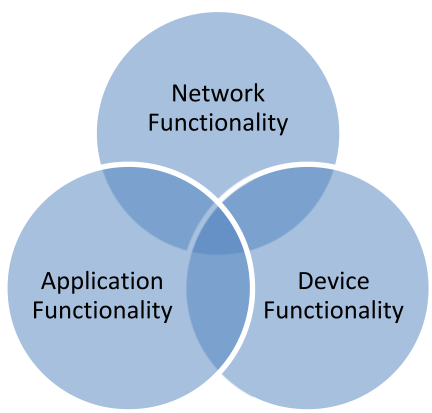

Figure 27: Functionality Relationships Leading to User Experience

Evaluators defined network functionality to include items such as area coverage and capacity. While these values were primarily confirmed by provided vendor analyses and the results of the Technical Survey (see Section 2.1 above), coverage and capacity issues manifested in the user experience primarily by whether or not users reported continued, uninterrupted access to the

[15] Notably, this network was optimized very quickly only a few days before the event and was optimized for outdoor use (i.e., not for in-building coverage). User training prior to accessing the network was limited.

network throughout their operations in areas where they were told to expect network coverage. Evaluators defined application functionality as the performance of the tasks built into the application. Assuming the device (and therefore the application) had sufficient coverage and capacity to operate, we noted user experience with navigating through the application, receiving accurate data from the application, etc. Evaluators defined device functionality as the user experience related to activating and deactivating the device, maneuvering through the various device screens, and the quality/performance of included hardware such as the camera, microphone, speaker, GPS receiver, etc.

Taken together, these analyses allowed us to draw conclusions about the overall user experience with the network. As was noted in Section 2.1 above, the perceived user experience is a function the combined influences of all of these factors. As much as we could draw some delineations between the various sources, these variables all interplay with one another to create the final network experience. Users may therefore unknowingly or erroneously blame the network for application flaws, blame the application for device issues, or blame the device for network shortcomings. Ensuring a seamless blend of these variables maximizes user benefit.

2.2.1 Network Functionality

User interviews and Evaluator experience highlighted a number of successful aspects, and some limitations, pertaining to the BC-14 demonstration network as deployed for this event. From a successes perspective, our interviews and experiences found:

- No noted examples of RF interference with the network. This finding is notable because of the large amount of RF in play throughout the event from sources such as the international media, enhanced commercial communication systems, etc.
- Very few examples of network interruptions or limitations with regard to network dependability. As a testament to the reliability of the BC-14 demonstration network, users relied upon it to move information when the LMR system covering the same area in Beaver Creek experienced dependability issues.

User interviews and Evaluator experiences also highlighted remaining challenges with the BC-14 demonstration network:

- Some areas within the purported coverage area of the network did not have coverage. Specifically, Evaluators and users noted coverage holes inside of buildings in the Vail Village. Evaluators understood that the system was NOT optimized for in-building coverage but many responders who used the devices did in fact attempt to use them from interior venues (e.g., staging rooms, the ECP, the VIP tents, etc.). Deployed Wi-Fi systems helped to provide additional in-building coverage but the in-building penetration of the system was not as thorough as public safety would need during day-to-day operations. This issue is worth considering for future demonstration networks as in-building coverage may be more mission-relevant than previously thought.
- The vast majority of user activity took place in the Vail Village area, putting more capacity loading onto one sector of the Vail Village eNodeB site. Some capacity issues (as shown with the occasional dropping of the surveillance video feeds in the ECP) could be attributed to insufficient capacity based on the locations of the eNodeB deployments. Network technicians agreed that, in hindsight, locating two nodes closer to the Vail Village would have been preferable.
- Use of a COW at the Beaver Creek venue provided solid coverage and capacity for the start/finish line venue but did not provide any coverage beyond that location. Users

reported walking out of coverage while completing their assigned tasks at that location. This issue was again a function of the design of the demonstration network and not necessarily a function of the network performance itself. It was simply a limitation of using a deployable system. It did, however, lead one user to request higher towers and better overall network coverage as the coverage lines became very salient to personnel in the field.

2.2.2 Application Functionality

Users and Evaluators alike experienced a number of successful aspects, and some limitations, pertaining to the two primary applications (i.e., ESChat and DragonForce) loaded onto issued devices for use on the BC-14 demonstration network during this event. From a successes perspective, our interviews and experiences found:

- Users provided favorable comments regarding the ability to setup and communicate via groups.
- User groups were configured according to roles.
- Users could send/receive role-based messages to/from multiple specific users with little effort using both proprietary applications.
- Users and Evaluators noted the clarity of audio using the push-to-talk function, even with significant background noise. Users stated that other applications/devices used for similar purposes did not perform as well with background noise.

User interviews and Evaluator experiences also highlighted remaining challenges with these applications. In many cases, the user experience varied between frequently using an application and using it a handful of times before becoming disinterested. Of specific note:

- Some users reported that the user interface of the applications was intuitive and user-friendly, yet evaluators noted little use of the majority of the available application functionality. Users seemed reasonably comfortable with basic functions but, by and large, did not explore within the application or make use of advanced features. Generally users found both applications functionally useful but noted inter-application differences with regard to user interface and ease of use. Users stated that the ESChat application was generally intuitive and easy to use, while the DragonForce application required added familiarization prior to use.
- Evaluators, who had the benefit of dedicated analysis time and no operational tasking during the event, spent a more intense period of time investigating the features of the applications. This “deeper dive” revealed some limitations in the application functionality that may have been design related or could be attributed to a lack of familiarization with the application. Training on both applications was brief and relatively shallow, leaving open the possibility that more in depth training and/or a longer time to develop a familiarity with the application would have produced a more refined use of that application.
- Both users and Evaluators noted issues with GPS accuracy using both applications. Evaluators noted that the GPS function within applications lacked the granularity needed to locate users/points of interest within a confined venue. As noted above, this issue could be application-driven or device-driven but, in either case, precludes using the applications for mission critical functions as the user location was simply too inaccurate to be tactically safe. Both applications did, however, provide an approximate enough location as to provide value in non-mission critical situations.

- Both applications were available to use on Evaluator personal devices in addition to their use on the Sonim devices. Both applications functioned differently on personal devices (both Android and iOS operating systems) than they did on the Sonim device. Given the likelihood that public safety professionals will use a variety of devices to support these applications, cohesiveness across platforms will become important.
- When using the Skype app, it did not appear that the Sonim devices (using Band 14) were able to pass video to the recipient of the Skype call. This finding was repeated on all Sonim devices issued to OEC/ICTAP, and was reported to Sonim technical personnel on site at the Vail ECP.

Evaluators lastly noted various future considerations with regard to each application. For ESChat:

- Evaluators were unable to paste hypertext links for dissemination of information via the messaging/chat function of ESChat. The internet is a great resource of information and the ability to send links to information derived from the internet is important.
- Evaluators could not locate a push-to-talk function within the ESChat application installed on personally owned devices (iPhone/Android cell phones).
- There was no “close” feature on the ESChat application, which forced users to go into the settings on the device and “force close” the app each time.
- The average call time of ESChat calls (in the statistics provided by OIT) of 71.34 seconds is substantially longer than average call durations seen on LMR networks, which tend to be somewhere between 5-20 seconds per call. Evaluators assumed that the reason for this extra length is due to the nature of the connection made with the app: calls remain open though not necessarily transmitting based on the resource determinations within the app itself.

For DragonForce:

- Although evaluators acknowledge that this finding may be a settings/training issue, they noted that if the screen timed out while using the DragonForce application, text and new file notifications were only slightly noticeable as a small buzz. Public safety personnel may require more overt alerts to important information.
- The DragonForce app occasionally reported inconsistent locations of users. This was seen on multiple BC-14 devices and on commercial devices. For example, Evaluators completed a test at the Lionshead bus stop but the DragonForce app geo-rectified device positions to the top of a parking garage across the street. This level of discrepancy can be significant for mission critical applications where the accuracy of field unit locations is a life safety issue.

2.2.3 Device Functionality

Mobile broadband devices are all but universal these days with many users carrying smart phones and others (especially in the public safety realm) carrying more than one. First responders frequently report carrying multiple devices (e.g., a personal device, a department-issued device, etc.). Most users, therefore, saw no immediate issue with operating a new device and reported being able to use the device reasonably quickly without in-depth training.

Of the comments provided by users specifically about the device, some notable inputs include:

- Some users desired cell phone capability on the BC-14 devices. Evaluators were able to complete VoIP calls via Skype on the devices but could not complete a standard cellular call and could not complete a video chat call using Skype on the devices. The provided Sonim devices were not equipped with a subscriber identity module (SIM) card that would allow for cellular phone capabilities.
- Users reported satisfaction with regard to the durability of the Sonim device. Evaluators saw the device thrown into the air several times and land on the ground with no noticeable damage or malfunctions.
- Users reported that using the devices was distracting at times and attributed this distraction to two factors:
  - A lack of planning regarding device assignment
  - A lack of more detailed training on the use of the device and primary applications.

Evaluators noted some additional considerations for this device or others that may be employed in a public safety role:

- The device itself was somewhat bulky but was not issued with a holster of any type. Users therefore had to place the device in a pocket, which nullified many of the notification/alarm features inherent in some of the applications. Furthermore, the bulk of the device may have been more problematic for smaller responders whose uniforms would, by extension, have smaller pockets. Smaller users also have smaller hands, which could make single-hand use of these ruggedized devices more difficult.
- The battery life on these devices was generally quite good. As with many other devices, however, when the device was outside of the network operating area and attempting to continually search out that network, the battery drained quickly.
- The power plug for the device was device-specific and proprietary to the vendor. On extended operations, the need to recharge communication devices become a very real logistics issue and utilizing a more universal charging cable would improve the deployability of these devices.

2.3 ECP and ICC Observations

Public safety personnel activated an ECP and an ICC in support of the 2015 FIS Alpine World Ski Championships. The ECP and ICC were co-located in the same room, housed within the Town of Vail's City Government/Police Department facility. The following section documents the results of interviews with personnel in the ECP and ICC.

The ECP served as the Incident Command function for the events in both Vail and Beaver Creek. The ECP was established on one side of a large open room, and included representation from the various local, state, and federal agencies, as well as NGOs responsible for managing public safety aspects of the events. ECP workstations were configured to provide sufficient space for each representative, and included VoIP telephone and internet access. ECP personnel were expected to bring their own computer, radio, and other technology resources, as needed. As the OEC/ICTAP evaluation period came near the end of the two-week long event, ECP personnel were not regularly observed utilizing the Sonim handheld devices nor either of the dedicated demonstration applications (DragonForce or ESChat). Consequently, this section will focus on observations and feedback from ICC personnel.

As indicated, the ICC was co-located in the same room with the ECP, situated on the opposite end of the room, but immediately adjacent to ECP personnel. The ICC was responsible for providing communications support to all local public safety agencies and disciplines assigned to the two event venues in the towns of Vail and Beaver Creek. The ICC was also in close proximity to the Vail Public Safety Communications/9-1-1 Center (PSCC) in the same building, which handles the normal day-to-day communications for public safety agencies and disciplines in Eagle County.

On one end of the room near the ICC area, staff configured a large video wall with multiple large flat panel monitors for situational awareness. The displays were easily visible to all personnel in the ECP and ICC. Monitor feeds could be configured as desired to display different sources, including weather, news, live feeds from event venues, security camera feeds, maps, internet browsers, and the web-based versions of applications being evaluated as part of the BC-14 demonstration network (specifically DragonForce and ESChat).

ICC STAFFING:

The ICC was operational each day, with hours varying as necessary to ensure Incident Dispatchers/Radio Operators were in place to coincide with hours of operation for the public safety agencies working the events.

The ICC was staffed with three personnel during event hours of operation. Staffing consisted of the following assignments:

- One Incident Dispatcher/Radio Operator for all public safety agencies working the Vail event venues
- A second Incident Dispatcher/Radio Operator for all public safety agencies working the Beaver Creek event venues
- One Incident Communications Center Manager (INCM)

The INCM was on the planning committee in preparation for the 2015 FIS Alpine World Ski Championships and participated in the decision surrounding designing, implementing, testing, and utilizing the BC-14 demonstration network. The INCM is also the Operations Support Supervisor for Vail's Public Safety Communications/9-1-1 Center. The INCM was responsible for scheduling personnel to fill the Incident Dispatcher/Radio Operator positions in the ICC as needed to support operations. The INCM developed a staffing plan that allowed different personnel from the Vail PSCC to rotate through and cover time slots in the ICC.

The public safety operational periods for the events began very early in the mornings and frequently ran into evening hours to coincide with various event-related activities. This allowed the INCM an opportunity to rotate several telecommunicators from the Vail PSCC through timeslots in the ICC in order to gain experience serving as incident or tactical dispatchers. The INCM was able to split each daily operational period into multiple shifts to accommodate the rotation of personnel, and to avoid having any one individual working abnormally long hours in that capacity.

ICC TECHNOLOGY:

The ECP/ICC was a temporary facility, established specifically for the purpose of supporting the 2015 Aspen World Ski Championships. Radio, telephone, and Computer Aided Dispatch (CAD) systems used in the ICC matched identically with the corresponding systems normally used in the Vail PSCC. This offered completely seamless interaction with the Vail PSCC, and eliminated the need for additional training for ICC personnel.

The primary technology systems used in the ICC consisted of the following:

- Radio consoles (2 Motorola® MCC7100 consoles, one assigned to Beaver Creek activities and one assigned to Vail activities)
- Telephone system (2 systems, one VoIP for administrative/non-emergency purposes and one Cassidian® 9-1-1 system)
- Computer Aided Dispatch (CAD) system (2 CAD workstations)
- Data systems

ICC workstations were configured for full internet functionality, allowing ICC personnel the ability to access the necessary situational awareness applications, databases, websites, etc. to support operations. Although the INCM was issued one of the handheld Sonim devices as part of the BC-14 demonstration network project, ICC personnel instead utilized the web-based demonstration applications (DragonForce and ESChat) which were installed and placed on the desktop of their computer workstations. ICC personnel were able to train on, practice with, and utilize the Sonim handheld devices, but using full computer workstations was more conducive to ICC operations.

Information from the ICC workstations and demonstration applications could be displayed on the video wall monitors for viewing by all ECP and ICC personnel.

2.3.1 Functions Used within the Devices and/or Applications

Personnel indicated they used computer workstations or handheld devices for the following functions:

- <u>Situational awareness:</u> for public information function and for monitoring communications among the groups configured in the demonstration applications.
- <u>Social media:</u> providing updates and public information to the community via their normal social media sites regularly used by the local jurisdictions.
- <u>Text messaging:</u> messaging with individuals and groups using both DragonForce and ESChat. In isolated cases, radio interference at one event venue on the LMR system resulted in the ICC using the text messaging function to communicate with specific operations personnel in the field.
- <u>Personnel accountability:</u> mainly for the law enforcement discipline. ICC personnel were able to use the demonstration applications to track the location of operations personnel in the field who were carrying the handheld Sonim devices. ICC personnel indicated they felt this application was extremely valuable to the safety of operations personnel by knowing the location of an individual as opposed to the normal automatic vehicle location (AVL) function which tracks the location of vehicles. ICC personnel also saw potential value for closest unit dispatching using this function. Even if they were not able to communicate by voice, they could direct other responders to the location of an individual if circumstances necessitated.
- <u>Map functions:</u> ICC personnel used the mapping functions to place locations of key items on a map which then became visible to other users with Sonim or personal devices. In one instance, this function was used to pinpoint the location of a reported suspicious vehicle.

- Still image/video upload/download: the demonstration applications supported upload/download of both still images and video clips. ICC personnel indicated they used this function occasionally over the course of the events for situational awareness and descriptive purposes. A still image of the suspicious vehicle described above was transmitted using this capability.
- Other: although not tested or utilized, the INCM indicated they had pre-scripted evacuation and emergency messages that could be transmitted either internally or externally as needed.

The INCM indicated that use of data functions is frequent and heavily relied upon in the ICC environment. Their normal ICC facility is a Mobile Communications Unit (MCU). Frequently used data applications and functions include CAD link, VoIP phones, 9-1-1 telephone system, MCC7100 radio consoles, local/state/national criminal justice systems, internet access, limited use of WebEOC®, social media, Google mapping functions, news, and weather. While operating out of an MCU, they would potentially rely upon BC-14 networks to support their data needs. While operating their ICC out of the ECP, however, they relied upon hardwired data networks within the Vail Police Department building. Choosing to locate the ICC within the Vail PD building, therefore, reduced the impact of the BC-14 demonstration network on ICC operations from a dispatch perspective.

2.3.2 Training on the BC-14 demonstration network

The INCM indicated all agency personnel received at least limited training (from “just in time” training of a few minutes to approximately 3 hours of more formal training) on the handheld Sonim devices and the two primary applications uploaded onto each device for non-mission critical use throughout the event. Additional just-in-time training was also provided for the ICC morning and afternoon shifts. The INCM indicated that both the devices and the applications were fairly intuitive and felt the level of training was sufficient for the given purpose.

ICC personnel did not, however, have much exposure to the devices or applications until one week prior to the events. After receiving the training and following moderate use, ICC personnel indicated they felt extremely comfortable using the devices and both applications. As described previously, due to the nature of the environment, ICC personnel almost exclusively used the applications from their computer workstations instead of the handheld devices. They felt the applications were easy to use, offered enhanced situational awareness capabilities, provided an alternate means of communications, and did not become a distraction.

2.3.3 Network Performance

The INCM indicated that she had an opportunity to utilize the handheld Sonim device as well as personal devices to evaluate the functionality of the network and the two applications. Overall, the INCM was impressed with the network and response time, and while she felt it might have been slower at times compared to commercial options, it remained consistent, and the response time did not negatively impact operations. At times, ICC personnel noticed a slight delay when monitoring the LMR bridge and when using the PTT voice functions in the applications.

2.3.4 Benefits & Desired Changes

ICC personnel liked the functionality of the applications, the rugged nature of the Sonim handheld devices, and the ability to bridge the BC-14 demonstration network and the LMR system, allowing personnel to hear radio traffic on their handheld devices. They also felt the concept of having a dedicated network that was not competing with other users on a commercial network was extremely important in creating a hardened resource that would be more reliable during actual emergencies. The one minor frustration expressed was the difficulty in force-closing the ESChat function (see section 2.2.2 above). While they recognized that their use of the demonstration network was not for mission-critical purposes, they expressed a desire to keep this resource on a long-term basis. They also indicated that they would not be losing any critical capabilities when the network was dismantled, as alternate means could be utilized to accomplish the same functions if necessary.

When asked how they would accomplish the same tasks in absence of the dedicated LTE network, BC-14 enabled devices, or the associated applications, ICC personnel indicated they would revert to either personal devices or other agency-issued devices on commercial networks. ICC and other public safety personnel were also able to install and utilize the same demonstration applications on their personal devices for use during the events. When asked for a comparison on functionality between using the applications on the dedicated Sonim devices and their personal devices, ICC personnel indicated they could not detect a noticeable difference, given their operating environment.

Overall, the INCM expressed extreme satisfaction with the network, devices, and applications demonstrated as part of the dedicated LTE network evaluation. As an organization, they felt this was an amazing opportunity, and that they were privileged to be part of this demonstration/evaluation project. She would definitely like to do whatever it takes to have the network in place on a permanent basis, although she was unsure of the associated costs involved.

3 OUTCOMES/FUTURE CONSIDERATIONS

Designing and deploying the BC-14 demonstration network successfully exhibited a number of key points that support local, statewide, and national efforts toward establishing a public safety broadband network.

3.1.1 Concept

The BC-14 demonstration network deployed in support of the 2015 FIS Alpine World Ski Championships demonstrated that private commercial entities possess the technical capabilities necessary to design, implement, test, and operate a public safety-dedicated broadband network. The industry partners involved in this demonstration successfully deployed a network utilizing BC-14 frequencies that supported non-mission critical communications throughout a real-world public safety event.

3.1.2 User Interest in BC-14 Devices

The BC-14 demonstration network deployed in support of the 2015 FIS Alpine World Ski Championships demonstrated that public safety agencies, when exposed to dedicated broadband network access, desire continued access to that network. User statements throughout the event, and specifically throughout OEC/ICTAP's evaluation period, emphasized their desire to keep the network operational beyond the end of this specific event. A desire for continued operation is a strong indicator that access to a dedicated public safety broadband network is valuable to response and emergency management personnel.

3.1.3 User Benefit

The BC-14 demonstration network deployed in support of the 2015 FIS Alpine World Ski Championships demonstrated that public safety can benefit from access to a dedicated public safety broadband network. Users performed functions, accessed information, and maintained situational awareness in ways that were either not available or not possible with the technologies provided for them on previous events. These functions, information, and awareness capabilities enhanced their ability to maintain the safety and security of the 2015 FIS Alpine World Ski Championships.

3.2 Future Considerations & Remaining Challenges

While this BC-14 demonstration network represents exceptional achievements toward utilizing the BC-14 spectrum in support of the public safety mission, work remains. The data reported in this assessment have limited generalizability in several key areas. Attempting to generalize or utilize the data beyond the scope reported here would be inaccurate and could result in damaging outcomes for future deployments or assessments. Some specific future considerations and limitations to consider are included below.

3.2.1 Public Safety Need

While providing this network to public safety professionals throughout the Vail Valley brought definable benefits, the network was not necessary to sustain operations. In part because of the restrictions placed on the deployment by the FCC STA, public safety agencies did not put mission critical communications across the BC-14 demonstration network. The information that did utilize the network, therefore, was non-mission critical. The exception to this statement occurred, on somewhat frequent occasions, at the Beaver Creek venue site where LMR coverage was poor but the provided LTE coverage was good. Field personnel quickly realized that they could communicate over LTE devices where they could not communicate over LMR radios, and, unsurprisingly, did so.

In order to demonstrate a true Proof of Need, future BC-14 demonstration networks will need to be hardened and implemented in such a way as to allow public safety and emergency management professionals to pass mission critical information over the network. Until then, the network remains a desirable if not necessary commodity.

3.2.2 Private/Public Partnerships

The BC-14 demonstration network, as deployed in support of the 2015 FIS Alpine World Ski Championships, is a unique but potentially repeatable model for other communities, depending on the resources available to that community. First, the public/private partnerships required to bring this network to reality are not commonplace nationwide. Colorado is to be commended here for building long term relationships with their vendor community and leveraging those relationships to the collective benefit of all involved. Communities who have not cultivated such relationships would not have the technical expertise or the equipment on hand to replicate the network constructed in the Vail Valley.

Second, many communities nationwide who play host to significant planned events do not have the budgetary resources available to fund the addition of this type of temporary network. The Colorado SPOC estimated that the vendor-donated equipment and services required to make this network a reality topped $250,000. Vendor generosity in this case was notable but cannot be expected on a nationwide basis, and individual communities in many parts of the country typically cannot afford to execute these types of demonstration networks within their event operational budgets.

Although the resources to execute this type of demonstration network are significant, the benefits are also significant. This type of network allows a community to perform testing, to assess plans, policies, and procedures, and, perhaps most importantly, to put devices into the hands of users and make a future capability real and tangible to that user.

3.2.3 Operational Usage

Generally, users provided favorable reviews regarding operational usage of the network/devices/applications. Users at the Beaver Creek venue specifically reported daily use and more frequent and detailed communications via the BC-14 demonstration network than its LMR counterpart (in part due to coverage issues with the designated LMR frequency for that area). LMR issues are not uncommon in this specific area, as users stated that there was little to no communications at previous events partly because public safety personnel feared congesting the network with unnecessary radio traffic. Busy signals, therefore, were a common experience on the LMR network but were not common on the BC-14 LTE network during this demonstration.

Evaluators noted the increased functionality available to public safety personnel via these applications. For example, with the combination of these applications, the devices, and the segregated network, users could perform the following functions:

- Remotely identify the locations of other users
- Send important and time-sensitive intelligence including detailed information and pictures/recordings to individual users and/or previously defined groups
- Chat, message, and/or push-to-talk with individual users and/or previously defined groups
- Stream audio and/or video
- File sharing
- Primary LMR monitoring (via patching)
- Communications with users/groups on outside networks (personally owned devices)
- General situational awareness including weather updates for events

Although users could access these functions previously via commercial LTE networks or, in some cases, LMR data networks, this BC-14 demonstration network allowed them to simply do more things more quickly than they had before.

3.2.4 Policy/Procedure Requirements

Vail Valley public safety agencies deployed this network for demonstrational purposes, and therefore supported the deployment with the minimal policies and procedures needed to support non-mission critical operations for the duration of the event. Going forward, however, agencies should leverage their communications, operations, information technology, and records management subject matter experts to develop policies and procedures regarding both future demonstration network deployments and, eventually, permanent access to and use of a public safety broadband network (and all associated devices and applications). These policies/ procedures should, at a minimum, cover:

- <u>Responder Safety:</u> Formalize deployment policies and procedures that maximize the viability and usability of the devices as communication tools while minimizing distraction and any risk to responder or citizen safety.
- <u>Evidentiary Data:</u> Formalize policies and procedures for the proper handling of evidentiary data produced, captured, or stored by devices or applications, and/or communicated via a dedicated public safety broadband network.
- <u>FOIA Information:</u> Formalize policies and procedures for the proper handling of data produced, captured, or stored by devices or applications, and/or communicated via a dedicated public safety broadband network, which is subject to the Freedom of Information Act (FOIA).
- <u>Data Storage/Retention:</u> Formalize policies and procedures for the proper retention of the data produced, captured, or stored by devices or applications, and/or communicated via a dedicated public safety broadband network. This issue becomes specifically salient with devices that take photographs, record video, or transmit streaming video for surveillance and/or evidentiary purposes.
- <u>Data Privacy:</u> Formalize policies and procedures for handling data produced, captured, or stored by devices or applications, and/or communicated via a dedicated public safety broadband network that contains private or personally identifiable information (PII). This issue becomes specifically salient with devices that take photographs, record video, or

transmit streaming video that may capture responder actions (e.g., entering in a PIN number on a debit card transaction, etc.) or citizen actions (e.g., items in plain sight while an officer is interviewing a witness in their home, etc.).

- Appropriate Device/Application Use: Formalize the distinction between appropriate and non-appropriate use of devices and applications on a dedicated broadband network. Consider issues such as prohibiting (or limiting) personal use, blocking certain applications, cautioning bandwidth-intensive applications, etc. Any use policy should consider network capacity limitations.
- Training: Formalize policies and procedures for required and recommended training on devices or applications operating on the dedicated public safety broadband network. Document an iterative training process which takes users from initial exposure to the devices and applications through the policies and procedures associated with those devices/applications into operational exercise/training scenarios using those devices/applications in a real-world setting. Address annual (or more often, as needed) refresher/requalification training.
- Security: Formalize policies and procedures for properly securing all the data produced, captured, or stored by devices or applications, and/or communicated via a dedicated public safety broadband network. Additionally, formalize the policies and procedures for securing the devices and applications, for user access (e.g., password requirements, biometrics, etc.), for responding to real or suspected security breaches, for responding to lost/compromised devices and/or data, etc. Frequently review network/device/application security measures to prevent the compromise of public safety intelligence and information.

3.2.5 Training Requirements

Expanded use of LTE technologies for public safety functions requires additional user training. While many of these devices are commercially developed to be user friendly, public safety user environments differ markedly from standard citizen use environments. It would be incorrect for an agency to assume that users can lateral skills learned on personal or department issued LTE devices today to BC-14 devices tomorrow without any specific policy, network, device, and application training. While experience with current devices will certainly make future training requirements simpler to accomplish and device usability more intuitive and comfortable, training is still required. Users during this event described a lack of formal training as correlated with instances of becoming “distracted” by the device, and Evaluators noted that a lack of intensive training prevented users from taking advantage of the full functionality of both the device and the applications on that device. Departments intending to adopt and heavily leverage BC-14 LTE technologies must plan for, develop, deploy, and evaluate training programs to accompany those technologies.

3.2.6 Deployable Equipment Limitations

The BC-14 demonstration network, as deployed in support of the 2015 FIS Alpine World Ski Championships, was a temporary network erected specifically to support a time-limited event. While it leveraged some permanent infrastructure assets, it heavily relied upon deployable temporary assets as well. As OEC/ICTAP Evaluators, event planners, and communication technicians all noted, relying on temporary deployable equipment presents significant challenges for short term and long term operations.

- <u>Time:</u> Technicians spent significant amounts of time rigging temporary devices into place, only to then remove those devices at the end of the event. Event planners need to consider the costs of this staff time in their event budget estimates, and also need to plan for venue access before, during, and after the event.
- <u>Localized Coverage:</u> Equipment deployed on a temporary basis is designed to support a specific event in a specific location. It does not support broader applications beyond this location. Public safety operations, however, do not always "honor" the borders of a given event envelope. In this instance, the COW deployed at the Beaver Creek site provided excellent access to the BC-14 demonstration network for responders near the start/finish line at the main grandstands. It did not, however, provide any access to the network in the Beaver Creek Village, parking lots, or any other areas near that COW deployment site. Had a responder engaged in any activity that drew them from the grandstands area into the larger Beaver Creek community, they would have exceeded the LTE coverage that COW provided and lost communication access. While coverage issues plague permanently mounted equipment as well, they are more noticeable and prevalent with temporarily deployed equipment.
- <u>Link Durability:</u> Because equipment is deployed ad hoc to support an incident or event and not specifically and permanently mounted at a given location, it often requires additional linkages to supply power or network connectivity. These linkages are prone to moisture damage (especially when tape or other protective steps fail) and can promote RF challenges just by the nature of the way RF travels through various different types of cabling. In one instance during the event, the Federal Bureau of Investigation (FBI) reported losing the video feed from a camera on the BC-14 demonstration network not because of a network failure but because the media unplugged the camera from the wall in order to use the outlet.
- <u>Equipment Durability:</u> Repeatedly installing and removing LTE equipment puts wear and tear on that equipment. While the equipment may be designed for field use, it may not be designed for all of the different climate or weather conditions it may face on various deployments. In Colorado, for example, a device must be able to withstand extremely dry air conditions in one situation and heavy, wet snow in another. A permanent housing can secure the electronics away from these conditions but a temporary deployment may/may not be able to fully protect the equipment.
- <u>Placement Access:</u> Oftentimes on an event, the ideal place to locate a key piece of public safety communication equipment is unavailable because that location is privately owned, is inside a secured area, or is otherwise the perfect place to locate higher profile equipment such as media antennas, a sound stage, etc. This issue came into play at the Solaris venue in Vail where technicians installed the Wi-Fi hotspots under the sound stage rather than in a more ideal elevated location because media equipment filled that location. Even temporary access on tower sites or high vantage points may come with a steep price tag as property owners know the event is in town for only a short period of time and seek to maximize their profits from that event. Locating public safety communication equipment inside secure event zones may protect the equipment but presents staff support challenges (i.e., credentialing, access, etc.) should that equipment fail or otherwise malfunction during the event. Furthermore, ideal locations from an RF perspective cannot always be secured, putting the equipment (and the communications relying on that equipment) at risk.
- <u>Appearance:</u> Because temporarily deployed equipment may not have access to an ideal location or ideal housing, technicians may need to improvise to allow the equipment to function properly in the event environment. In Vail, technicians placed Wi-Fi antenna

and router equipment inside clear protective housing to keep the equipment protected from snow and melting water. The devices needed power so the technicians connected them to small car-type batteries inside the Tupperware boxes. Only after construction did the technicians realize just how suspicious these devices would look to an outside observer, and took lengths to secure them away from public sight and let personnel who would be using those locations know what the boxes contained.

- Cost: Deploying, testing, and then removing LTE equipment is expensive for a community. The costs provide a valid network for their use during a dedicated timespan but they retain no benefit from the investment once the event is concluded and the equipment removed. This issue came into play in the Vail Valley area as public safety professionals who utilized the network wanted to keep their access to it long term but were unable to do so.

These challenges make deployable systems a less desirable solution for public safety communications than permanently constructed networks. Deployable solutions are a good alternative to provide ancillary coverage during an event/incident that, for example, requires greater network capacity, or to provide network access during an event/incident in a location that otherwise does not support public safety operations on a sufficiently frequent basis to warrant permanent coverage. When possible, fiscally beneficial, and operationally supportable, however, permanent network solutions are preferable to temporary solutions.

3.3 Future Testing Recommendations

Based on the testing of the BC-14 demonstration network, OEC/ICTAP developed the following recommendations regarding any future testing of LTE system deployments:

- **Test equipment should be used that is capable of recording persistent, more accurate, and a larger set of measurements.** While many applications available on smartphones and other broadband-capable devices are low-cost, easy to use, and sufficient for at-a-glance monitoring of a single LTE sector, dedicated LTE scanner test equipment is absolutely required for performing a thorough, highly accurate, robust, and holistic analysis of system performance.
- **All LTE commercial carriers should be represented in all phases of testing, and their coverage footprints, equipment type and quantity, and high level design requirements should be obtained prior to testing.** As stated throughout this report, there were no T-Mobile handsets available to OEC/ICTAP at the time of testing. For future testing, in order to properly measure network performance of BC-14 against commercial networks, evaluating all commercial carriers in the testing area is recommended. Regarding coverage footprints, commercial carriers provide an estimate of their broadband coverage to the NTIA, and some companies publish coverage maps on their websites. However, it should be noted that these coverage maps may not have accompanying technical parameters to allow for proper comparisons. Therefore, commercial coverage footprints should be used as a general guide for evaluating where their system will potentially allow users to access the network, but not necessarily provide full service.
- **Efforts should be made to determine the location of commercial carrier LTE sites.** If commercial carriers will be evaluated along with BC-14, verifying site locations with commercial carriers may help to explain anomalies in performance data such as very high or very low data rates in certain places.

- **Sufficient preparation time on-site should be allocated to verify performance and mitigate any technical issues with test equipment.** The iOS device used by OEC/ICTAP to measure performance of the Carrier A LTE network experienced technical issues such as inconsistent GPS readings and network connectivity problems. Ideally, issues such as these should be resolved prior to the start of any testing.
- **If possible, attempt to obtain network performance data from the system operator.** LTE systems are capable of storing a large amount of detailed information regarding system operations, including core network statistics, as well as eNodeB and user equipment performance. If the testing and evaluation period allows for this level of analysis, pursue reports generated from the system vendor. Review any vendor-provided data objectively to ensure that it is complete.

4 CONCLUSION

The BC-14 demonstration network fielded in support of the 2015 FIS Alpine World Ski Championships was a successful and remarkable example of the power of public/private partnerships to produce a definable benefit for the public safety community. The State of Colorado, Town of Vail, Eagle County, and all of their public safety and vendor partners conceived of, designed, implemented, and utilized a public safety-dedicated LTE network that improved user access to broadband data services throughout the event.

In total, the successes of the network, even when tempered by the noted areas for future improvement, demonstrate the value of providing responders with access to a ubiquitous, permanent nationwide public safety broadband network. The true benefit of this type of demonstration network came from its ability to:

- Provide users with the opportunity to experience the benefits of the network firsthand.
- Provide administrators with the opportunity to make tangible what once was theoretical, engaging executives in lasting discussions on the need to support and prioritize public safety broadband efforts.
- Provide researchers with the opportunity to learn from deployment decisions and operational requirements in order to further improve user access to this dedicated spectrum in the future.

APPENDIX A REFERENCE MATERIAL

Federal Communications Commission (http://www.fcc.gov/encyclopedia/special-temporary-authority)

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Public Safety Demonstration Network Operational Plan (Draft, dated 28 January 2015).

Wendelken, S. (2015, February 17). Public-safety LTE pilot exposes necessity of private network. *Mission Critical Communications*. Retrieved from http://mccmag.com/onlyonline.cfm?OnlyOnlineID=509.

Vail Valley Foundation; 2015 Vail Beaver Creek World Championships http://www.vvf.org/athletics/2015-world-championships

National Telecommunications and Information Administration; Broadband USA – Colorado http://www2.ntia.doc.gov/colorado

Quarterly Performance Progress Report for Broadband Infrastructure Projects, June 30, 2014 http://www2.ntia.doc.gov/files/grantees/nt10bix5570157_adams_county_communications_center_inc_ppr2014_q2.pdf

Quarterly Performance Progress Report for Broadband Infrastructure Projects, December 31, 2014 http://www2.ntia.doc.gov/files/grantees/nt10bix5570157_adams_county_communications_center_inc_ppr2014_q4.pdf

US Department of Commerce; Broadband Technology Opportunities Program (BTOP) Adams County Communications Center, Inc. (Grant Award NT10BIX5570157) http://www2.ntia.doc.gov/files/grantees/20120511095538760.pdf

Colorado Governor's Office of Information Technology; FirstNet Colorado http://www.oit.state.co.us/strategy/firstnet

Federal Communications Commission; Special Temporary Authority http://www.fcc.gov/encyclopedia/special-temporary-authority

APPENDIX B ASSESSMENT DATA COLLECTION FORMS

B.1 Technical Survey Sheet

GENERAL INFO	OEC Name:		
	First Responder Name/ID:		
	Date:		
	Approximate time at the start of testing:		
	Device type (Handheld / MDT / Other):		
	Device (Sonim / Apple / Samsung / Other):		
	Device OS (iOs / Android):		
RTR-Nettest	Open app. Run test.		*Comments:*
	Successful (check box):	Unsuccessful (check box):	
SignalCheck (Lite or Pro)	Open app. Confirm that the device is using LTE, not Wi-Fi. If the Wi-Fi info lists an SSID, you may need to disable the Wi-Fi in the device to test LTE.		*Comments:*
	RSRP (dBm):	RSRQ (dBm):	SNR (dB):
	CQI:	Provider:	GCI:
	TASK	**EXPERIENCE** 1 = Poor, 5 = Excellent	**COMMENTS**
Dforce	Send text message to another recipient in group. Confirm receipt.	1 2 3 4 5	
	Add text to map. Have another tester confirm its successful addition.	1 2 3 4 5	
ESChat	Complete a Push to Talk call. Test for inbound and outbound audio.	1 2 3 4 5	
Skype	Complete a VOIP call to another tester. Test for inbound and outbound audio.	1 2 3 4 5	
Google Earth	Attempt to have the app zoom to your location, and view the nearby satellite imagery.	1 2 3 4 5	
YouTube	Watch a video (make sure it's not one that you've watched previously on this device).	1 2 3 4 5	
Streaming Video	Attempt to access a streaming video feed (if FBI cams not available, perhaps DOT cameras).	1 2 3 4 5	
		1 2 3 4 5	
		1 2 3 4 5	
		1 2 3 4 5	
		1 2 3 4 5	
		1 2 3 4 5	

B.2 Operational Data Collection Sheet

Location/Date/Time:			
Home Agency		Incident Role	
Device Used		Tech Savvy?	
App(s) Used			

For What Functions Did You Use Your Issued Device(s)?					
Situational Awareness	☐	Personnel Accountability/Tracking	☐	Video streaming, upload, and/or download	☐
Weather Conditions/Updates	☐	Mapping/placing resources, venues, personnel, etc.	☐	Still image upload/download	☐
Social Media ______________________	☐	Map functions (routes, distances, terrain, etc.)	☐	Document/file sharing	☐
Email	☐	Database Inquiries (wants, warrants, NCIC/CCIC, etc.)	☐	Document creation	☐
Text Messaging	☐	LPR	☐	CAD Functions	☐
Group Messaging	☐	AVL	☐	RMS/Reporting Functions	☐
Other?	☐	Please Describe/Identify			

Operational Questions
In general, how often do you use data/LTE technologies in your role? (frequently/rely on it, important occasionally, rarely important, never used)
Tell us about the training you received on the network before this event? The device? Each app?
Before you came out on the event, did you feel comfortable with the device/app? How much have you had a chance to use it? Do you feel more comfortable now?
Is the device/app easy to use? What has it helped you do? Has it been distracting at all?
What do you like about the network/device/app? Any features that have been a real benefit to you? Any that you would change? How/why? Any that you would just get rid of?
Is there anything this network/device/app DOES NOT do that you wish it did?
How would you rate the network performance/response time when using this device during this event? (excellent, adequate, slow/inadequate)
If you were not using this network/device/app, how would you accomplish the same tasks (or could you)?
Any part of the network/device/app that works BETTER than if you were just using your own personal device? Worse?
Given a chance, would you want to use this network/device/app again? Would you want to carry it on a daily basis as part of your normal gear? What obstacles would prevent you from incorporating this technology in your daily role?

APPENDIX C LIST OF ACRONYMS

Item/Acronym	Definition
ADCOM911	Adams County, Colorado / Communications Center
AVL	Automatic Vehicle Locator
BC-14	Band Class 14
BTOP	Broadband Technology Opportunities Program
CA	Carrier Aggregation
CAD	Computer-Aided Dispatch
COML	Communications Unit Leader
COW	Cell on Wheels
DAS	Distributed Antenna System
DHS	Department of Homeland Security
DIA	Dedicated Internet Access
DL	Downlink
ECP	Event Command Post
eNodeB	Evolved Node B (Mobile Telecommunications Technology)
FBI	Federal Bureau of Investigation
FCC	Federal Communications Commission
FirstNet	First Responder Network Authority
FIS	Fédération Internationale de Ski
FNC	FirstNet Colorado
FOIA	Freedom of Information Act
Gbps	Gigabits per second
GD-MS	General Dynamics Mission Systems®
GPS	Global Positioning System
ICC	Incident Communications Center
ICTAP	Interoperable Communications Technical Assistance Program
INCM	Incident Communications Center Manager
iOS	iPhone Operating System® (Apple)
LMR	Land Mobile Radio
LTE	Long-Term Evolution
Mbps	Megabits per second
MHz	Megahertz
MCU	Mobile Communications Unit
NGO	Non-governmental Organization
NPSBN	National Public Safety Broadband Network
NTIA	National Telecommunications & Information Administration
OEC	Office of Emergency Communications
OIT	Office of Information Technology

Item/Acronym	Definition
PSCC	Public Safety Communications/9-1-1 Center
PTT	Push To Talk
RAN	Radio Access Network
RF	Radio Frequency
RS	Reference Signal
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SIM	Subscriber Identity Module
SINR	Signal to Interference plus Noise Ratio
SME	Subject Matter Expert
SMLA	Spectrum Manager Lease Agreement
SNR	Signal to Noise Ratio
SPOC	State Point of Contact
STA	Special Temporary Authority
SWAT	Special Weapons and Tactics
SWIC	Statewide Interoperability Coordinator
UL	Uplink
VIP	Very Important Person
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network

APPENDIX D GLOSSARY

Item/Acronym	Definition
Download speed	Measured in megabits per second (Mbps), download speed is the average number of megabits per unit of time that pass between a transmission leaving a remote transmission device and arriving at a local receiving device.
Latency	Measured in milliseconds (ms), latency is the measure of a time delay experienced within a communication system
Mean	Synonymous with Average
Median	In a given dataset, the median is the data point in the sequential center of the data. For example, in a data set with 11 numbers, the median is the 6th number when viewing the data sequentially.
Standard deviation	In a given dataset, the standard deviation describes the square root of the average amount that all data points vary from the mean. It is frequently used to evaluate how widely dispersed a data set is and indicates the level of variability in that data. Higher standard deviations are associated with more variable data.
Upload speed	Measured in Mbps, upload speed is the average number of megabits per unit of time that pass between a transmission leaving a local transmission device and arriving at a remote receiving device.