Datacasting:

Houston Super Bowl LI

Video Systems Integration, Implementation, Deployment, and Evaluation Report

First Responders Group

May 2017

Homeland Security
Science and Technology

Intentionally Blank

Datacasting:

Houston Super Bowl LI Video Systems Integration, Implementation, Deployment, and Evaluation Report

May 2017

Prepared for:	**The First Responders Group Office for Interoperability and Compatibility**
Prepared by:	**Johns Hopkins University Applied Physics Lab**

Homeland Security

Science and Technology

Publication Notice

This document was prepared under funding provided by the U.S. Department of Homeland Security Science and Technology Directorate (Contract Number N00024-13-D-6400; Task Order 0372, Task Number S8906, Resilient Systems for Public Safety Communication). Points of view or opinions expressed in this document are those of the authors and do not necessarily represent the official position or policies of the U.S. Department of Homeland Security.

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) assumes no liability for this document's content or use thereof. This document does not constitute a standard, specification, or regulation. Additionally, JHU/APL does not endorse particular products or manufacturers. Trade and manufacturer's names may appear in this report only because they are considered essential to the objective of this document.

Acknowledgements

The authors wish to express their sincere appreciation to: Dennis Storemski (Director, City of Houston Mayor's Office of Public Safety and Homeland Security), Chris Newport (Chief of Staff, Houston Host Committee), Jack C. Hanagriff (Project Manager, City of Houston Mayor's Office of Public Safety and Homeland Security), the City of Houston Police, Fire, and Public Works Departments, Harris County, SpectraRep, Axis Communications, Verizon, PrefTech, VidSys, Siklu, IDIS Global, Edge 360, and Houston First.

Principal Author: Morgan Gaither (JHU/APL)

Contributing Authors: Dan Syed, Steven Babin, and John Contestabile (JHU/APL); Mark O'Brien (SpectraRep); Jack C. Hanagriff (City of Houston Mayor's Office of Public Safety and Homeland Security)

Contact Information

Please send comments to:
Mr. John Contestabile, Program Manager, JHU/APL
11100 Johns Hopkins Road
Laurel, MD 20723-6099
Phone: 443-220-8090
E-mail: John.Contestabile@jhuapl.edu

Disclaimer

The views and opinions of authors expressed herein do not necessarily reflect those of the U.S. government. Reference herein to any specific commercial products, processes, or services by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. government.

The information and statements contained herein shall not be used for the purposes of advertising, nor to imply the endorsement or recommendation of the U.S. government.

With respect to documentation contained herein, neither the U.S. government nor any of its employees make any warranty, express or implied, including but not limited to the warranties of merchantability and fitness for a particular purpose. Further, neither the U.S. government nor any of its employees assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed; nor do they represent that its use would not infringe privately owned rights.

Intentionally Blank

Table of Contents

Disclaimer iv
1 Introduction 9
2 Background 11
2.1 Super Bowl Preparations 13
2.2 Public Television Network Testing 14
3 Houston Super Bowl Overview 17
3.1 Houston Public Safety Communications Architecture 17
3.2 Provision of Equipment to Support Super Bowl Security 21
3.3 Sensors 21
3.4 Communications 25
3.5 Applications 26
3.6 Super Bowl Datacasting for Video Data Transport 27
3.7 Key Stakeholders 27
3.8 Timeline & Milestones 29
4 Super Bowl Video Solution Observations and Outcomes 29
4.1 Temporary Video Network at Discovery Green Park 29
4.2 Datacasting 30
4.3 Datacasting and Cellular Measurements during Super Bowl LI 31
5 Conclusions 33
6 References 35
APPENDIX A: Abbreviations and Acronyms 36
APPENDIX B: Technical Details of Datacasting 37
APPENDIX C: Notes from 13 January 2017 Meeting with City of Houston, HPD, and HFD 44
APPENDIX D: Results of Super Bowl (SB) Video Solutions Operational Test at the January 2017 Houston Chevron Marathon 45
APPENDIX E: Additional Discovery Green Maps 51
APPENDIX F: Measurement Results from Comparison of Datacasting and Cellular Communications during Super Bowl LI 56

Figures

Figure 1: City of Houston Super Bowl LI Event Locations 10
Figure 2: Timeline for Datacasting Technical Experiments and Events in Houston and Harris County 12
Figure 3: 2016-2017 Timeline for DHS Preparations for Super Bowl LI 13
Figure 4: Discovery Green Map 18
Figure 5: Houston Super Bowl Public Safety Video Communications Architecture 20
Figure 6: Super Bowl Live Temporary Video Camera Locations (at Discovery Green Park) 23
Figure 7: Discovery Green Park Camera Network Diagram 24
Figure 8: COWS for Enhanced Commercial Cellular Coverage for Super Bowl 26
Figure 9: Datacasting Status Screen 32

Intentionally Blank

Executive Summary

For the past two years, the Johns Hopkins University Applied Physics Laboratory (JHU/APL) has been supporting the Department of Homeland Security (DHS) Science and Technology Directorate (S&T) First Responders Group, Office for Interoperability and Compatibility, in a series of technical experiments for the deployment and evaluation of enhanced telecommunications architectures for first responders. The primary goals of these architectures are to increase resilience during emergencies and more effectively meet the needs of first responders, especially their need for more data-centric communications. JHU/APL efforts have centered on—but not limited to—integration of a datacasting capability into public safety communications architectures in Chicago, IL, Boston, MA, and Houston, TX. Each of these technical experiments has expanded on the previous one to include more government agencies and additional telecommunications technology.

Datacasting leverages existing public television station infrastructure and capacity to provide secure, targeted delivery of data, including real-time video streams. Data content is encoded, encrypted, encapsulated, and multiplexed into the television station broadcast signal. Registered end users with UHF/VHF receivers and the datacasting software can receive the television signal and decode the information within it. As a broadcast medium, datacasting provides an efficient and scalable mechanism for wide dissemination of large data files and video. Because it uses the robust public television infrastructure, it also provides a highly reliable alternate communications pathway during extreme weather and emergencies, when power losses and network congestion can degrade cellular-based communications.

DHS S&T and JHU/APL worked closely with the City of Houston Office of Public Safety and Homeland Security, Harris County Central Technology Services, and a number of private sector vendors to enhance the public safety telecommunications architecture in Houston, TX in preparation for security operations during Super Bowl LI, which was a National Special Security Event. The Harris County (which surrounds the city of Houston) and Houston area is a FirstNet early adopter site, and already had a forward-leaning public safety communications architecture, integrating one of the nation's first Band 14 Long Term Evolution (LTE) public safety networks and a prototype datacasting capability.

In preparation for the Super Bowl, the City of Houston Office of Public Safety and Homeland Security worked with industry partners to enhance the city's surveillance camera suite and provide the necessary connectivity to command centers. DHS S&T worked with the local governments to enhance datacasting capability and integration and provided additional resources to Harris County to increase its presence on Band 14. Harris County Central Technology Services and the City of Houston Office of Public Safety and Homeland Security had enhanced situational awareness through the introduction of applications to support geo-location, collaboration, and real-time video streaming. As a result, public safety officers in Houston had access to a resilient, data-centric telecommunications architecture to support security during the Super Bowl.

JHU/APL engineers participated in the evaluation of this architecture through observation of ongoing operations, interaction with end users, and a series of measurements of download capacity performed in and around some of the largest Houston events during Super Bowl weekend (February 3 – 5, 2017). Based on observations and end user feedback, the JHU/APL team confirmed the improved situational awareness and incident-free operation of the system under loaded conditions. End users emphasized the utility of video in mitigating the limitations and ambiguity inherent in verbal descriptions, which thereby enabled more confident decision-making. While capacity can be augmented in specific areas by adding a network of microcells, cell-on-wheels (COWs) or a Distributed Antenna System, areas outside of these targeted areas can have severe congestion potentially affecting the delivery of video to first responders. This suggests that a system such as datacasting, dedicated exclusively for first responders, should have a real benefit to public safety. The utility of datacasting was confirmed when JHU/APL observed the presence of a sizable area, especially in the blocks around crowded venues in which commercial cellular capacity was degraded while datacasting capacity remained unchanged.

1 Introduction

Under the direction of the US Department of Homeland Security (DHS) Science and Technology Directorate (S&T) First Responders Group/Office for Interoperability and Compatibility, the Johns Hopkins University Applied Physics Laboratory (JHU/APL) was tasked with performing a series of technical experiments for testing and evaluating an enhanced integrated telecommunications architecture for use by public safety during events involving mass gatherings and events that are of national or international significance. Each of these technical experiments expanded on previous ones by including new technology architecture and a broader user community. This report describes the most recent technical experiment where this enhanced public safety communications architecture was used to support security operations during Super Bowl LI, which was a National Special Security Event (NSSE) that took place in Houston, Texas, in February 2017. For the past two years, DHS S&T and JHU/APL have been working with the City of Houston Office of Public Safety and Homeland Security to implement and evaluate integrated network solutions aimed at enhancing both the performance and the resilience of public safety communications in Houston and Harris County (the county surrounding the City of Houston). In addition, the City of Houston Office of Public Safety and Homeland Security has worked with a number of private sector companies, including Verizon, VidSys, IDIS, and Axis Communications, to enhance its video surveillance capabilities. As a result, the City of Houston and Harris County were able to deploy a comprehensive network of video cameras, handheld device applications, and resilient communications networks to achieve enhanced situational awareness in support of public safety during Super Bowl LI.

Previous large-scale events held in Houston, like the 2016 NCAA Final Four Tournament, indicated a need for redundant video system capabilities at highly attended venues. For Super Bowl LI, these highly attended venues included the Super Bowl LI game at NRG Stadium and the nine-day Super Bowl Live festival at Discovery Green Park, located about seven miles northeast of NRG Stadium (see Figure 1). As a result, the City of Houston worked with Verizon, VidSys, and Axis Communications to install a temporary video communications network to cover events associated with Super Bowl LI. DHS S&T supported the continued deployment and expansion of datacasting capabilities for public safety end users, including the Houston Fire Department (HFD), City of Houston Office of Emergency Management, and Houston Police Department (HPD), as a way of providing efficient video sharing and greater communications resiliency. In addition, Harris County Central Technology Services (CTS) installed applications to support geo-location and collaboration, and purchased a substantial number of Band 14 capable handheld devices. DHS S&T supplemented this effort through the purchase of a significant amount of “loaner” communications equipment and through installation of an application to support real-time video streaming (for use in conjunction with datacasting). The result was an integrated architecture of sensors, communications, and software applications designed to provide resiliency and more robust data delivery.

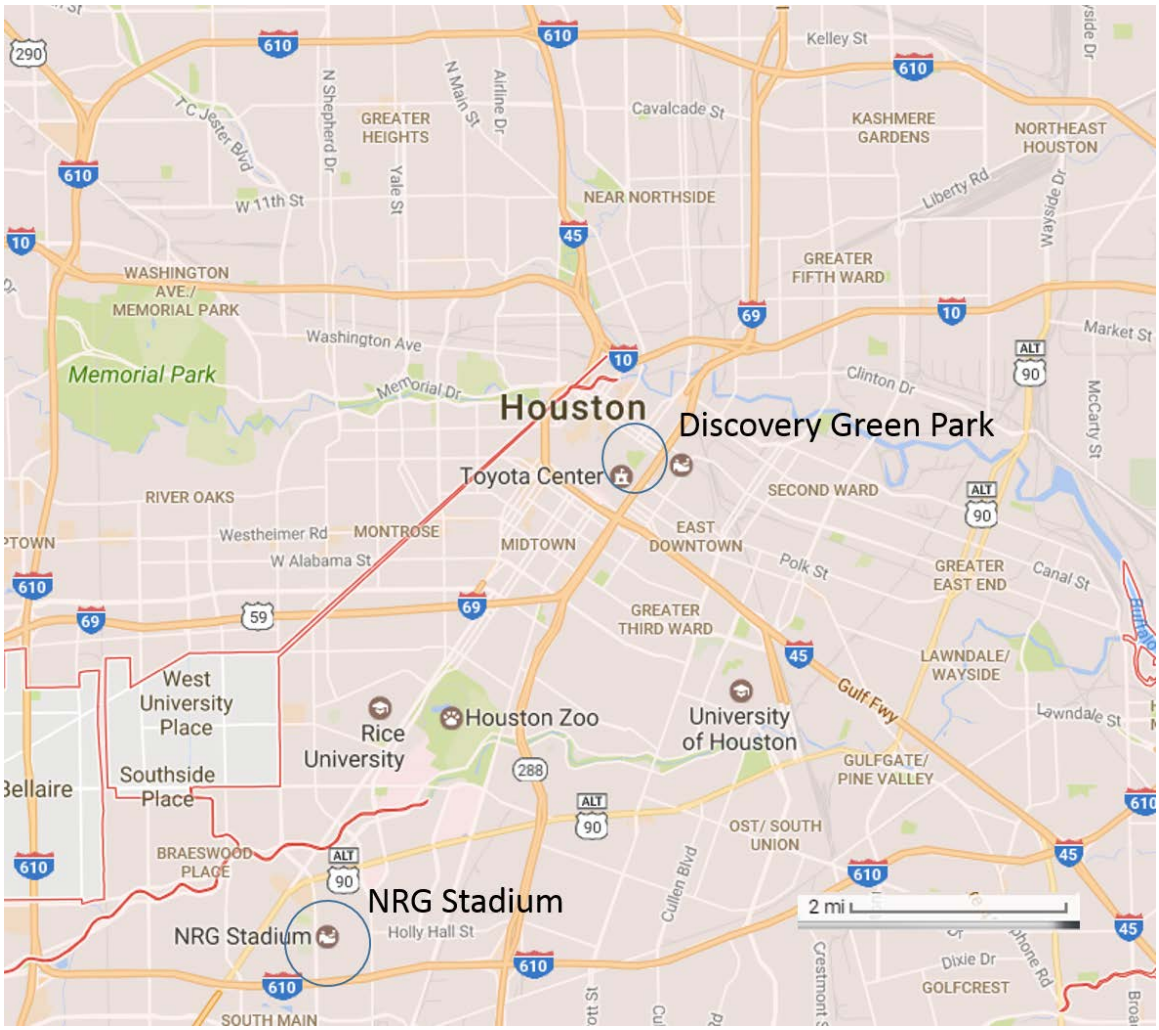

Figure 1: City of Houston Super Bowl LI Event Locations

Although there were no adverse incidents of sufficient magnitude to stress the architecture during the Super Bowl, the architecture functioned very well. There were no reported disruptions in communications, and initial end user feedback indicated that the integrated architecture provided increased situational awareness. Because the end users were occupied executing their public safety mission, it was not possible to collect comprehensive data regarding end-user attitudes toward the enhanced architecture during the event. Nonetheless, the limited end user feedback available confirmed the desire for greater access to data and the importance of video in supporting decision-making. The ability to view incidents via video and not be dependent on verbal descriptions reduces ambiguity and uncertainty and can lead to more confidence in the decision making process.

Finally, the Super Bowl and the nine-day Super Bowl Live festival provided the DHS S&T test team an opportunity to validate the concept that datacasting can provide a highly reliable redundant communications path during emergencies and can deliver video and other data during times of cellular network congestion. JHU/APL executed a substantial number of measurements of both datacasting and cellular data download performance both in crowded areas and around the periphery of the most densely attended venues. Those measurements corroborated one of the most valuable use-cases for datacasting: Its use as a redundant communications tool in locations where cellular communications are limited due to bandwidth congestion. Interestingly, these measurements also suggest that, while temporary augmentation of the existing infrastructure mitigated the effects of congestion within the event area, there is still a large

region around the periphery of these events – an area in which first responders might have to operate and have command centers – where increased congestion limited network access. These tests and the resulting measurements are sufficient to warrant additional study and efforts to reproduce and verify the results. For the convenience of the reader, a list of acronyms and abbreviations is provided in Appendix A.

2 Background

JHU/APL has been supporting DHS S&T Directorate First Responders Group, Office for Interoperability and Compatibility, in the development of integrated public service telecommunications architectures as a way of providing first responders more resilient communications capabilities. One effort has centered on integrating a datacasting capability into existing public service architectures, and technical experiments have been performed previously in Houston TX, Chicago IL, and Boston MA.

Datacasting leverages available capacity in digital television signals to provide secure, targeted one-way communications for first responders. It provides data capability lacking in land mobile radio (LMR) and is more resistant to extreme weather and bandwidth congestion than cellular based solutions. It can also be a more efficient mechanism for achieving one-to-many communications. However, it provides only one-way transmission capability and has limited capacity. A detailed technical description of datacasting can be found in Appendix B.

An initial meeting between DHS S&T and the City of Houston/Harris County occurred in February 2015. Based upon this meeting, an agreement was reached to implement, test, and evaluate a datacasting capability to support public safety in Houston and Harris County.

Since February 2015, JHU/APL has worked with DHS S&T in conducting a series of technical experiments to evaluate the feasibility and effectiveness of datacasting as part of an integrated communications network for public safety. Critical objectives of this testing have included the following:

- Evaluation of the utility of datacasting in support of day-to-day operations: A primary goal of previous tests was to present datacasting in an operational context to end users in order to validate the utility of content that can be provided using datacasting. The emphasis of this effort has centered on assessing the value of datacasting as a tool for disseminating real-time video and on evaluating the ability of disparate organizations to use datacasting to achieve rapidly deployable interoperability.
- Identification of integration issues: As a result of testing, JHU/APL has been able to identify, and in some cases work with the datacasting technology provider (SpectraRep) to mitigate, issues associated with the integration of datacasting into a larger public service network. Some of these issues are attributed to the limitations inherent in a prototype architecture. Except for a fully-operational datacasting capability implemented in Clark County Nevada, the architectures evaluated by DHS S&T and JHU/APL have been temporary integration solutions implemented for evaluation purposes. Other integration issues have revolved around system capacity. Although television stations have an average 2 to 2.5 Mbps of bandwidth capacity available to be allocated for public safety transmissions (and that capacity could be increased by an order of magnitude in a true emergency), implementations evaluated by JHU/APL have been limited to approximately 1 Mbps. A critical goal of recent tests has been to assess the risk of bandwidth saturation and to propose ways of preventing degradation of the system due to users attempting to push too many concurrent video streams.
- Needs assessment: A third objective of operational tests involving first responders is to obtain increased understanding of the needs and requirements of the public safety community.

These technical experiments were associated with a number of public events in which datacasting was used operationally in support of security. As each event occurred, the testing included an expanded public safety user community and evolving public safety communications network architecture. Figure 2 contains a timeline of key events in Houston and Harris County.

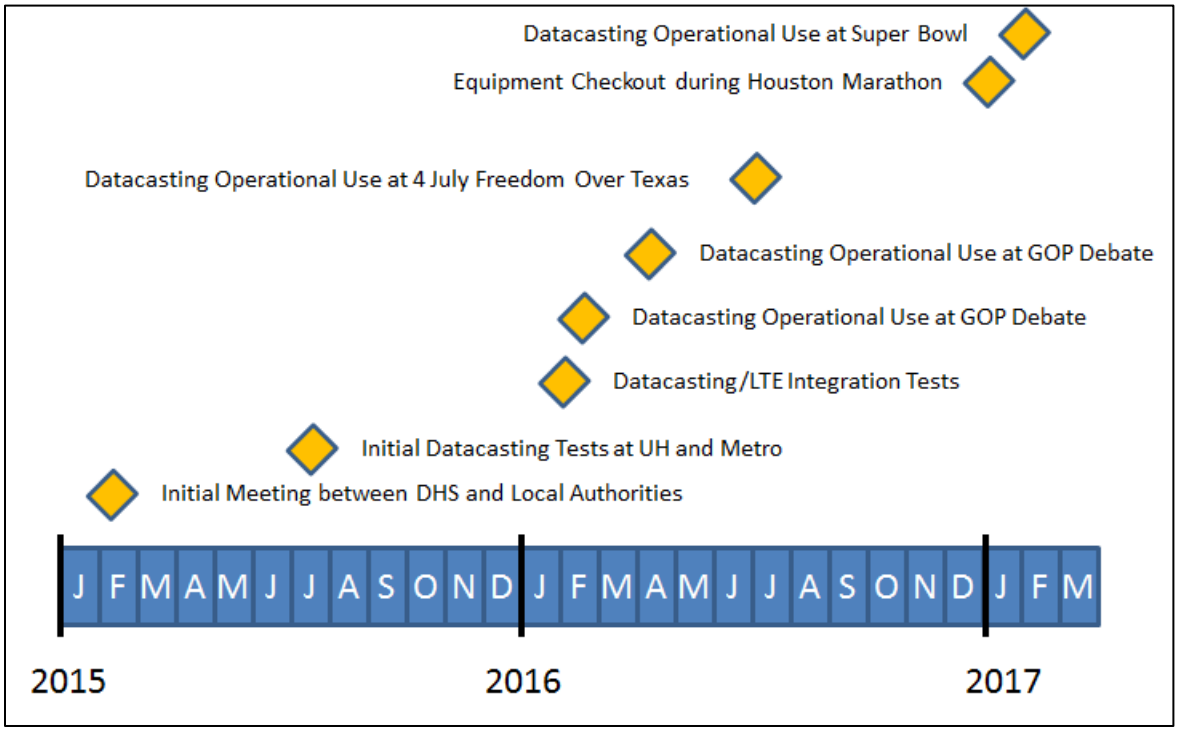

Figure 2: Timeline for Datacasting Technical Experiments and Events in Houston and Harris County

After discussions with critical stakeholders in the Houston/Harris County area, it was decided that two initial tests would be performed. The first would be a simple test of the utility of video distributed via datacasting, and the second would be a test of both utility and interoperability. In preparation for this testing, datacasting equipment was integrated into Houston Public Television station KUHT and into the University of Houston Emergency Operations Center (collocated with KUHT). Detailed test plans were generated and provided to the stakeholders so their feedback could be incorporated into updated test plans. After a number of iterations, agreement was reached on a final test plan and the procedures to implement it.

In July 2016, two pilot tests of the datacasting capability were executed, one on the campus of the University of Houston and the other on the Houston Metro light rail between the NRG Stadium station and the Texas Medical Center station. These tests served as initial technical capability demonstrations and were documented in Reference (a).

The next set of tests of the datacasting system was performed in February 2016. During this set of tests, datacasting was integrated with a number of cellular LTE networks including the local commercial provider, the dedicated Band 14 LTE public safety network, and a deployable ad hoc network developed by Parallel Wireless for use in areas without cellular network availability. In addition, the datacasting implementation was expanded to enable transmission to be initiated from both the University of Houston Emergency Operations Center and the City of Houston Emergency Operations Center, and bandwidth load tests were performed to assess whether the system would degrade gracefully under extreme load stress conditions. Details of this testing are contained in Reference (b).

One result of the February 2016 testing was that City of Houston public safety officers expressed a desire for the video solution developed by SpectraRep to support testing of datacasting. SpectraRep integrated an application developed by Wowza to enable live video data to be streamed in real-time from a handheld device via cellular to a datacasting IncidentOne dashboard for injection into the KUHT digital television signal. At the request of the City of Houston, this capability was expanded and used operationally to support security operations during the February 2016 Republican Party Presidential Debate and during the NCAA Men's Basketball Championship Finals in April 2016. This additional feature enables public safety communications to leverage both cellular and datacasting simultaneously for greater resiliency. Observations from the Debate are documented in Reference (b); observations from the Men's Basketball Finals are documented in Reference (c). Datacasting was also used operationally in response to flooding in Houston that occurred later in April 2016, as described in Reference (d).

Datacasting was used operationally with an expanded portable surveillance capability during the Fourth of July "Freedom over Texas" events in 2016. Two companies, IDIS and Edge 360, worked together to develop a joint surveillance solution to fill gaps in public safety situational awareness in Houston. A portable video surveillance capability was deployed during the Freedom over Texas Festival in Eleanor Tinsley Park. Datacasting was used to distribute video from the portable video system. Observations from the Freedom over Texas Festival are documented in Reference (e). The City of Houston is presently beginning to use datacasting operationally on a more routine basis.

2.1 Super Bowl Preparations

Preparations for the Super Bowl began (for the DHS team) at the end of October 2016. Figure 3 summarizes those efforts and their timing.

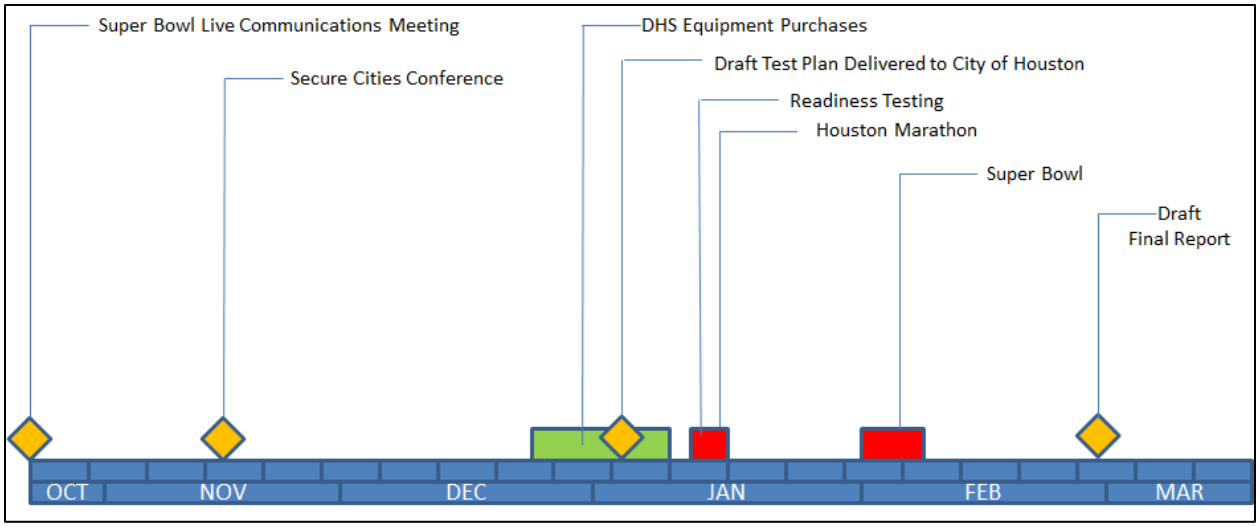

Figure 3: 2016-2017 Timeline for DHS Preparations for Super Bowl LI

During the last week of October 2016, representatives of JHU/APL made site visits to venues for events planned during the week of the Super Bowl and attended meetings between public safety officials from the City of Houston, Preferred Technologies (PrefTech), VidSys, Axis, and Verizon to discuss requirements for additional cameras and fiber (both permanent and temporary) to support security at the various public venues. As a result of these meetings, JHU/APL began drafting descriptions of each venue and an initial test plan. A draft test plan was delivered to the City of Houston at the beginning of January 2017.

An important coordination meeting took place during the Secured Cities Conference on 15-17 November 2016 in Houston TX, when representatives of DHS attending the conference had the opportunity to

interact with representatives of the City of Houston. It was also agreed that DHS would purchase equipment – including 50 Sonim XP7 phones – as a loan through its contract with JHU/APL for use during the 2017 Super Bowl. Members of JHU/APL worked with representatives of Harris County to identify and purchase the desired equipment.

On 13 January 2017, a meeting was held with representatives of HPD, HFD, and the City of Houston in which end-user feedback was acquired. During this meeting, the Houston public safety community participants expressed enthusiasm for datacasting and the capabilities it provided. There was a strong desire to expand its role within the overarching public safety architecture. Because of this, HPD expressed significant interest in the use of datacasting to disseminate video from helicopters, live feeds from the Houston Public Safety Video Network (PSVN), etc. Therefore, it was decided to expand the datacasting configuration to include a datacasting installation at the HPD Real-time Crime Center (RTCC) for Super Bowl LI. Further details of this meeting can be found in Appendix C.

During the Houston Chevron Marathon held 14-15 January 2017, the DHS test team, including JHU/APL and SpectraRep, performed a series of readiness tests to ensure that the datacasting elements within the public safety architecture were ready for use during the Super Bowl. SpectraRep provided training and equipment configuration while JHU/APL verified the communications pathways. This effort is documented as Appendix D to this report.

For the February 2017 Super Bowl, public safety situational awareness and communications were substantially augmented by both additional permanent and temporary cameras and communications. A number of commercial applications were deployed by various public safety agencies within the Houston Public Safety community. The number of users who could inject data and video into the datacasting system and the number of users who could receive datacast data was expanded to its greatest level to date. As such, security operations for the Super Bowl provided DHS a unique opportunity to test an integrated public safety communications architecture including datacasting under conditions required to support a major NSSE.

2.2 Public Television Network Testing

The broadcast television distribution path has several native attributes that provide unique value to public safety communications, including that it is already constructed and operational, operates on licensed spectrum, and is natively multicast (one-to-many). While it is not natively two-way, work has been done to integrate datacasting with other communications networks to provide some two-way functionality.

The native multicast model allows for an unlimited number of recipients for any content that is broadcast. At the same time, distribution can also be limited to specific users or groups. This targeting is managed by selectively allowing decryption based on a pre-installed token on the receiver device that is registered with the content management server.

Like traditional television content, encrypted public safety video, files, and alerts can be transmitted to an unlimited number of recipients without consuming any additional bandwidth. There is, however, a limit to the number of independent content streams that can be transmitted concurrently over any given bandwidth allocation from the TV station. In preparation for the Super Bowl, we conducted tests using WHUT Public TV in Washington, DC, at various transmission data rates to evaluate acceptable parameters for how many separate video streams could be transmitted at various over-the-air data rates.

Television stations are assigned a 6 MHz wide channel in either the VHF or UHF television broadcast band. The current Advanced Television Systems Committee (ATSC) broadcast television standard provides for this 6 MHz channel to transmit MPEG transport packets at a fixed rate of 19.3 Mbps. Television stations allocate that capacity to various program streams including high definition (HD)

video, standard definition (SD) video, audio, closed captioning, and metadata. Because they decide how much to allocate to each program service, they typically fill the entire transport stream with content.

For example, a station may run one HD channel at ~12 Mbps, and 2 SD channels at ~4 Mbps each to fill up the program stream. Newer encoders can produce acceptable video quality at even lower rates, allowing for potentially a third SD or two HD program streams.

When datacasting is deployed, stations allocate some spectrum off the top to that service, effectively reducing bits available to services targeting traditional television viewers. For example, a station allocating 1 Mbps to datacasting would then fit all of their traditional programing into 18.4 Mbps. Using 2 Mbps for datacasting would yield 17.4 Mbps, etc. The DHS team tested datacasting throughput at 2.0 Mbps, 1.5 Mbps, and 1.0 Mbps. In each case, additional independent video streams were injected until degradation was noticed.

A typical datacasting allocation from public television broadcast partners is 1 Mbps. Some stations allocate more on a fixed basis. Up to 3 Mbps has been allocated full-time to datacasting in some cases. Whatever the station allocates as a baseline is available to public safety full-time 24/7.

It should be noted, however, that public television has offered to make more bandwidth available for short periods when circumstances dictate. For example, during and after a disaster, Public Television has agreed that the highest and best use of their spectrum may be to allocate more to public safety in order to allow more individual streams to be broadcast concurrently to those users.

Enabling this short-term bandwidth increase requires a change at the station to increase the bandwidth allotment and then a corresponding increase in output on the datacasting side. This could be automated in the future, a capability that may be examined later.

It should also be noted that video quality is not easily objectively classified. Subjective observation is still the primary way to quantify what is acceptable from what is not. Complicating this is the fact that not all video has equal bitrate requirements to produce acceptable quality. Video of scenes containing lots of motion is more bandwidth intensive than relatively static scenes. The difference can be significant. Modern digital codecs like H.264 (used for datacast video) use a combination of I-frames, which are full or key frames, with P-frames and B-frames that convey only what has changed in each frame. Since P and B frames only show what has changed, they require less bandwidth when not much is changing within the scene. For example, the amount of change in a talking head shot, where essentially only the lips are moving, would be much less than for a basketball game where almost every pixel is different from frame to frame.

Video bandwidth requirements also vary throughout the encoding process. Allocating a hard bandwidth limit would result in having not enough bandwidth some of the time and too much at other times. Statistical multiplexing allows multiple video streams to occupy a shared bandwidth allocation instead of individual hard bandwidth allocations per stream. This can reduce the impact of high and low demands by dynamically allocating more or less as needed to any individual stream from the overall pool on a frame-by-frame basis.

The SpectraRep datacasting technology uses a process similar to statistical multiplexing to manage multiple video feeds in the bandwidth allocated to datacasting. A SpectraRep video encoder manages each video feed. These encoders share their status with the other encoders feeding the same broadcast television transmitter.

When a new video stream announces itself, it polls to determine if there is enough bandwidth to begin streaming at its highest settings. If not, the encoders will determine how to reduce the quality of other streams to make room for it. This dynamic encoding allows more streams to fit into a given bandwidth

allocation, but makes objective quality measurement difficult because of the constantly changing requirements for each stream. For example, if the minimum parameters were set low enough, then it could be possible to transmit double the number of streams at lower quality.

The codec used to encode also plays a significant role in bandwidth requirements. Newer codecs like HEVC (H.265) are twice as efficient as current codecs like EVC (H.264), which is twice as efficient as MPEG-2. In other words, going from MPEG-2 to H.265, as broadcast television is about to do under ATSC 3.0, would yield a 4x reduction in bandwidth requirements for the same content.

With that background, SpectraRep performed the following experiments after the Houston Marathon and before Super Bowl LI in order to evaluate how many "typical" datacast video streams could be injected into a broadcast television signal using H.264 encoding at various allocated data rates. The purpose was to see how many video data streams could be simultaneously transmitted by datacasting before bandwidth consumption degraded reception. They attempted to introduce a controlled amount of motion in each video by moving the camera at the same rate for each test. Tests started with 1 Mbps and new streams were added until video quality was noticeably degraded. At four concurrent streams, degradation was perceived by some observers, but not all.

At 1.5 Mbps, noticeable degradation did not appear until there were six streams. At 2.0 Mbps, seven video streams were transmitted with minimal degradation. However, CPU usage on the receiver laptop computer was now at 100%, so while the bandwidth may have been able to accommodate additional streams, the laptop displaying them would have introduced local quality reduction due to an inability to render all of the streams.

It should also be noted that the host computer was displaying both the video previews in the datacasting dashboard and the videos received over-the-air, so a total of 14 videos were being displayed at the time CPU usage started to become an issue (this will vary depending on the age of the computer, video graphics card capabilities, and other factors, so it should not be considered an absolute). The SpectraRep dashboard allows users to pause videos of less interest to conserve local host processing power for the streams they do want to see.

3 Houston Super Bowl Overview

3.1 Houston Public Safety Communications Architecture

The City of Houston has been working with DHS S&T over the last two years to implement a datacasting capability to provide more efficient delivery of video and larger files, and a redundant communications path to provide greater resiliency during emergencies and in the presence of network congestion.

In addition, Harris County already had one of the nation's most forward-leaning public safety communications architectures. Harris County is a FirstNet[1] early adopter site and has implemented one of the nation's first FirstNet compliant Band 14 Long Term Evolution (LTE) networks dedicated to public safety.

As mentioned above, there were primarily two heavily attended venues associated with Super Bowl LI: NRG Stadium and Super Bowl Live, which was at Discovery Green Park located about seven miles northeast of NRG Stadium (Figure 1). Discovery Green Park is a twelve-acre public park shown in Figure 4. The Houston public safety communications architecture was augmented with temporary infrastructure in order to support the Super Bowl Live events in Discovery Green Park.

[1] FirstNet is the named commonly assigned to the National Public Safety Broadband Network established as part of the Middle Class Tax Relief and Job Creation Act of 2012 and being implemented by the First Responder Network Authority (also referred to as FirstNet).

Figure 4: Discovery Green Map[2]

The Super Bowl LI video communications efforts focused heavily on improving video capabilities in and around Discover Green Park in support of Super Bowl Live events. The objective of this task was to deploy a temporary video solution based on an integrated architecture consisting of a number of telecommunications technologies that support/augment the existing City of Houston PSVN. This camera network offered additional camera views to public safety personnel that were not previously available on the existing City of Houston PSVN due to technology restrictions or physical obstructions from signage and other temporary structures at the venue.

In order to facilitate the installation of an improved network, the City of Houston Mayor's Office of Public Safety and Homeland Security requested support from the Houston Super Bowl Host Committee in obtaining the necessary permissions to temporarily install cameras in the required locations within Discovery Green Park. Installation included use of poles, stages, and other temporary gate structures to ensure optimal camera views.

The City of Houston Office of Public Safety and Homeland Security worked with private industry partners to implement additional cameras and network connectivity for Discovery Green Park. The

[2] Source: http://www.discoverygreen.com/discovery-green-park-map

expanded architecture included permanent features that were in place prior to preparation for the Super Bowl and added equipment (e.g., cameras, fiber optic communications) provided by event sponsors. Some of the newly installed architecture/equipment was removed post-event, while others remain in Houston permanently. This expanded architecture is represented in Figure 5.

For purposes of this report, elements of the architecture are classified as sensors, communications, and applications. While the newly installed video system primarily was focused on Discovery Green Park, the end users (both in command posts and mobile units) had access to a number of cameras located in other parts of the city through the existing Houston PSVN.

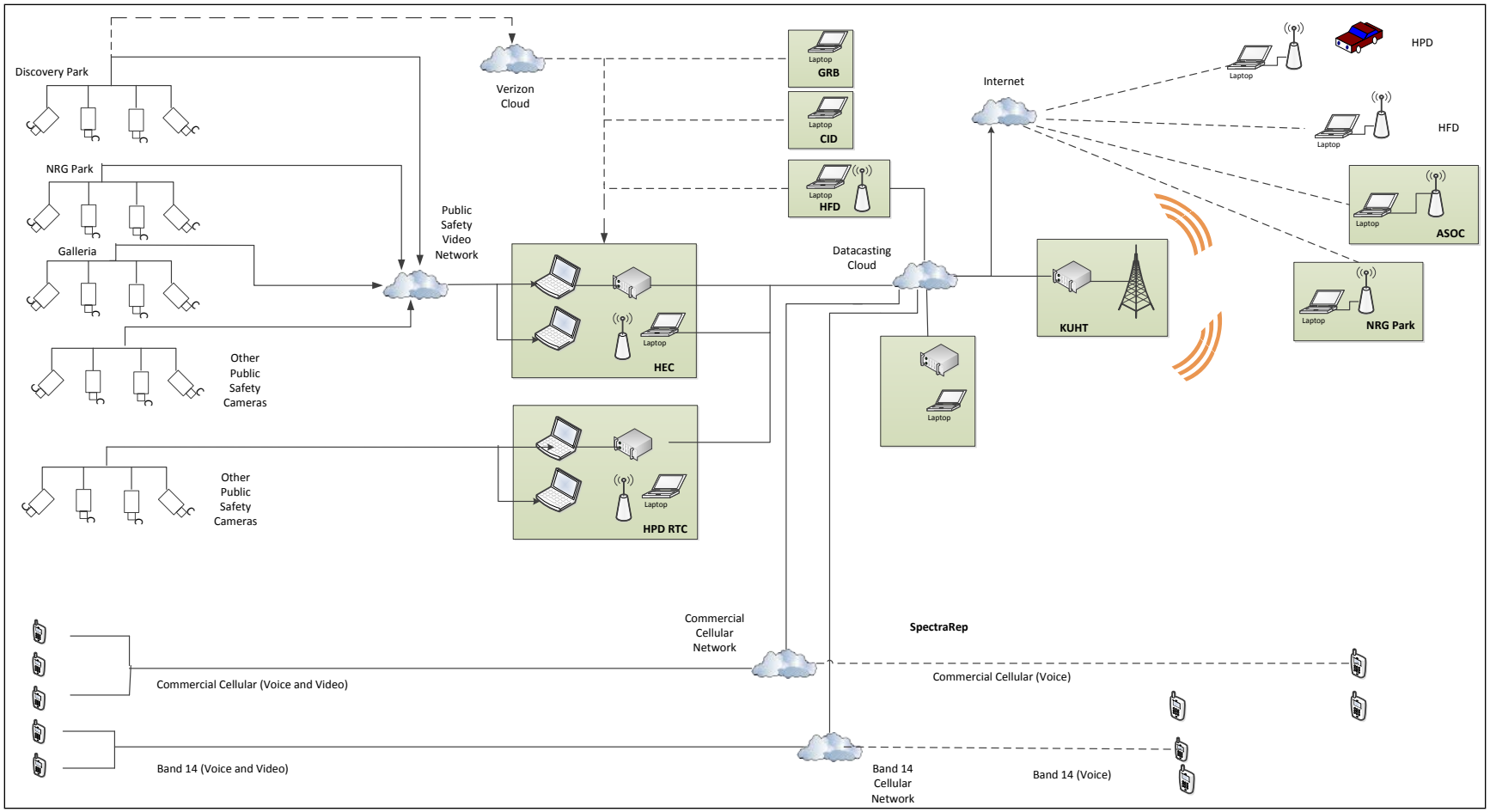

Figure 5: Houston Super Bowl Public Safety Video Communications Architecture

3.2 Provision of Equipment to Support Super Bowl Security

As part of efforts to evaluate the effectiveness of an augmented public safety communications network during the Super Bowl, DHS S&T purchased equipment to enhance operations using the Harris County Band 14 LTE for Public Safety Network. Additional equipment to be lent to the City of Houston was identified by Harris County CTS Public Safety Technology Services and purchased by JHU/APL. It was shipped to Harris County to support security operations during the Super Bowl. The equipment will be returned to JHU/APL and used in future communications network tests for DHS S&T. Table 1 below provides a description of the equipment purchased.

Table 1: Equipment Purchased to Support Super Bowl Security

Item	Vendor	Quantity
Sonim XP7 Phones	Sonim	50
XP7 Belt Clips	Sonim	50
Bluetooth 4.0 LTE Push to Talk Button	Klein Electronics	30
PTT Headsets	Klein Electronics	50
Standard Stereo Headsets	Bittium	300
20.5"x11.5"x7.5" Pelican cases with wheels	Omni Manufacturing	20
10 Port USB Hubs	Anker	10

3.3 Sensors

The City of Houston has a number of public safety cameras, third party private industry cameras, and TranStar traffic cameras, which feed into their PSVN. All involved partners such as HFD, HPD, and EOC have access to the PSVN through the VidSys software.

A Super Bowl sponsor, Axis Communications, provided additional cameras for the Super Bowl during the nine-day Super Bowl Live Festival. Video from these cameras was distributed to the Houston PSVN and cloud-based servers provided by Verizon. Both networks supported redundant video distribution and allowed end users to take advantage of video analytics. The need for this redundant capability was originally discovered during NCAA Final Four when the City of Houston had to leverage a third party temporary network hosted by NCAA Operations.

Cameras deployed at other locations such as NRG Park and the Galleria, as well as traffic cameras, were connected to the EOC via the city's existing PSVN. Video from the newly installed cameras was provided to the EOC, to a temporary command center in the George R. Brown Convention Center (GRB), and to the HFD. Video from the city's public safety cameras distributed using the existing PSVN was also accessible at the HPD RTCC in downtown Houston.

To support and expand datacasting capabilities, video transcoders were installed at both the EOC and at the RTCC (the video transcoder at the RTCC was borrowed from the University of Houston EOC for this event). At each location, a pair of computers was integrated with the video management systems (VMS) to provide access to public safety video. These computers were set to "push" data onto the datacasting cloud making it accessible for over the air transmission via Houston Public Media (KUHT–TV) or via internet transfer to users of the IncidentOne datacasting dashboard. It should be noted that, during Super Bowl LI security operations, the datacasting dashboard was run on tablets connected to the Internet via Wi-Fi; however, the application could also have run on a mobile phone and received data via a cellular network.

The City of Houston, in conjunction with the Super Bowl Host Committee, implemented a video communications solution that allowed users to access and control a network of temporarily placed cameras, which accommodated access from the Houston Public Safety Video Platform – VidSys Physical Security Information Management, or Web Browser via Internet through the cloud. Primary users (see Table 2) were stationed in the GRB forward command post, Houston Police RTCC, and the City of Houston Emergency Operations Center (EOC).

Table 2: Super Bowl Live Temporary Network End Users

Location	No. of Users	No. of Simultaneous Video Streams per User	Total No. of Simultaneous Streams per Location
GRB Forward Command Post	4	8	32
HPD RTCC	1	8	8
HEC EOC	2	8	16
SB Operations	1	8	8
Texas DPS	1	8	8
Texas DOT	1	8	8

In the planning for Super Bowl Live, public safety personnel anticipated that "high use" cameras would include the major Access Control Points (ACP) and large crowd venues:

- ACP #1 – 900 Avenida de las Americas
- ACP #2 – 1600 McKinney Street
- ACP #3 – 1300 Caroline Street
- ACP #7 - 1100 Avenida de las Americas
- Zone #3 Concert Stage (3 Cameras) – 1300 La Branch
- Discovery Green A/8 Stage – 1000 Avenida de las Americas

To support views of these areas, continuous monitoring was used for cameras located at ACP#1, ACP#2, ACP#3, and ACP#7, with additional usage during concerts/entertainment at the Zone #3 and the Discovery Green stages. Up to three work stations and three mobile applications were requesting video feeds from up to eight video streams. The camera installation locations supporting these operational efforts are indicated in Figure 6, below, and in additional figures provided in Appendix E. Figure 7 shows the network diagram for these cameras.

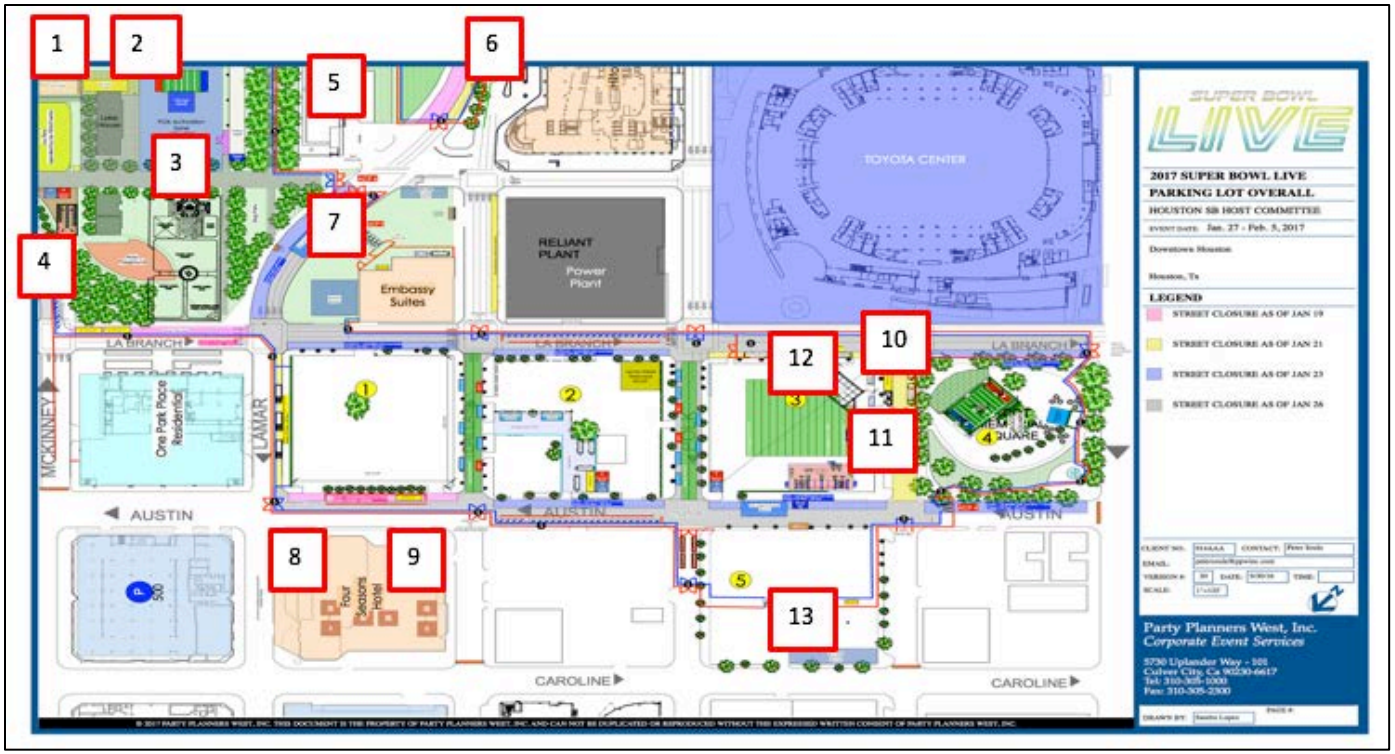

Figure 6: Super Bowl Live Temporary Video Camera Locations (at Discovery Green Park)

Super Bowl 51 – Discovery Green
Camera Network

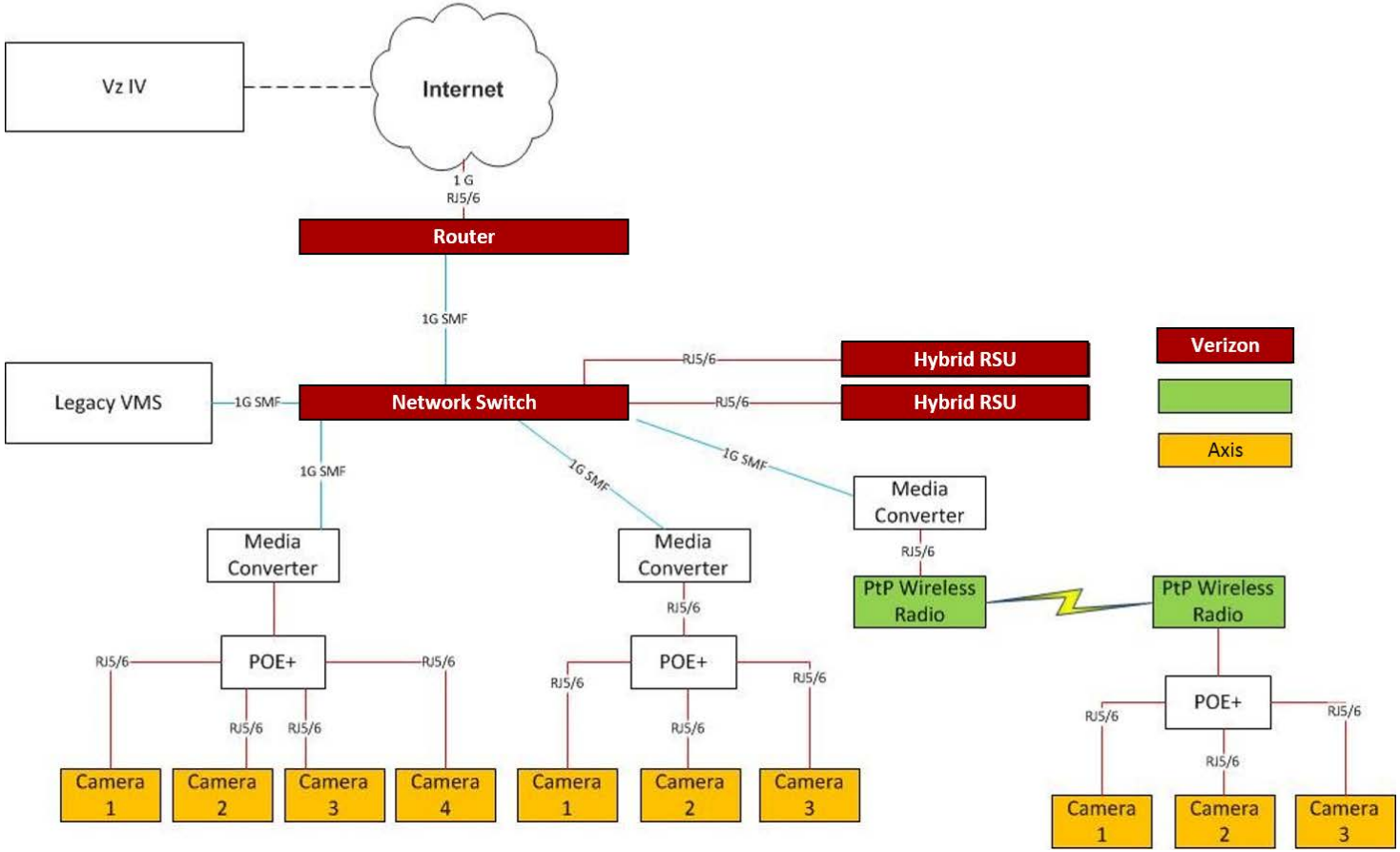

Figure 7: Discovery Green Park Camera Network Diagram

The augmented system for Super Bowl Live used:

- Point-to-point wireless communications
- Existing and available fiber, in addition to newly installed fiber
- LTE broadband
- Pan-tilt-zoom (PTZ) and fixed cameras
- Intelligent video technology
- Live and recorded video
- Mobile video (handheld devices)

All cameras communicated through wired (fiber), wireless radio, or cellular connection. Additional requirements were as follows:

- Deployment: The installation/deployment shall be easy and repeatable.
- Operation: The camera system shall operate independently but support an existing video system if desired.
- Installation: The cameras shall be configured for temporary placement and not interfere with other wireless solutions.
- User Access: The cameras/network shall accommodate command and control needs from multiple locations including HPD Forward Command in GRB, HPD RTCC-1200 Travis, and City of Houston EOC.
- Coverage – The camera views shall include coverage of major entry and exit points, areas of potential densely packed crowds (stages and high profile attractions), VIP/Dignitary Venues, and any threat areas identified by law enforcement. Coverage in areas not accessible by fixed cameras shall be augmented by handheld mobile phone cameras.
- Camera Type – While PTZ cameras are preferred, fixed or other camera solutions will be considered as long as the designated viewing requirements can be covered. Cameras should offer both day and night time viewing.
- Video Management System – The associated VMS shall support video play back and storage for later viewing and possible export.
- Backhaul – The camera system shall accommodate wired or wireless backhaul.
- Optional – Intelligent video technology such as video analytics for detection of perimeter breach, suspicious package, or object tracking may be used.

3.4 Communications

A critical aspect of the public safety telecommunications architecture used to support Super Bowl security operations was that it included a significant number of redundant networks:

- **Commercial Cellular**: The majority of officers within HPD and HFD use LMR for voice and commercial cellular phones operating on the local Verizon network for communications. In preparation for the Super Bowl, the cellular infrastructure in areas hosting Super Bowl events was significantly upgraded. Additional fiber and cable were integrated and a large number of Cell on Wheels (COWs) were deployed around the city (see Figure 8). The temporary LTE cellular infrastructure was provided by Verizon, as they were one of the Super Bowl sponsors.

Figure 8: COWS for Enhanced Commercial Cellular Coverage for Super Bowl

- **Harris County Band 14 LTE for Public Safety**: Harris County is a FirstNet early adopter site and has one of the nation's first and most extensive FirstNet compliant Band 14 networks. It provides some jurisdictions in Harris County with a dedicated network for public service. However, there is somewhat limited coverage and not every public safety officer is equipped with a mobile device compatible with Band 14. Therefore, approximately 200 Sonim XP-7 phones were added (including 50 on loan from DHS S&T) to cover the Super Bowl.
- **Datacasting**: During the Super Bowl, datacasting transmission authorization capability (i.e., the ability of public safety officials to broadcast video and data/file content) was limited to the EOC, the HPD RTCC, and the HFD. However reception capability was implemented in a number of HPD and HFD vehicles and tablet computers.
- **Cloud Services**: Cloud services were used to connect additional cameras deployed for the events of Super Bowl week to the EOC, TX Department of Transportation (DOT), TX Department of Public Safety (DPS), Harris County Mobile Command, the GRB command post, and HFD. Additionally, cloud services were used to support distribution of video data to KUHT for over-the-air transmissions and to the datacasting dashboard via Internet/cellular.

3.5 Applications

Public safety operations during the Super Bowl provided an opportunity to integrate and evaluate a number of applications developed for use on cellular phones. Four applications in particular were used prominently as part of the security operations.

- **Geolocation**: TRX Neon was implemented on a number of HPD devices in order to provide Smart Targeting and Identification via Networked Geolocation ("STING"). Operational testing of this capability was a critical test objective for Harris County during the Super Bowl.

- **Collaboration**: Harris County also implemented the "Moxtra" collaborative platform on a significant number of phones. This application enabled first responders to rapidly establish chat groups and exchange images and other content.
- **Real-Time Video Streaming**: In conjunction with datacasting integration, the Wowza Media Systems "GoCoder" application was loaded onto a number of HFD and HPD phones. Use of this application enabled efficient dissemination of real-time video streams from handheld devices via LTE/Internet (using the IncidentOne dashboard) and over-the-air broadcast via datacasting.
- **Digital Sandbox Mobile Indicator**: The Mobile Indicator enables mobile users of Digital Sandbox 7 (DS7) to submit photos and observations from the field. Submitted reports and the locations from which they were submitted are instantly uploaded and available in DS7 for use by command post or operations center personnel.

3.6 Super Bowl Datacasting for Video Data Transport

Datacasting was used by the City of Houston and Harris County to increase operational capabilities to transmit live video streams from the field to fixed and mobile command posts, and to link video capabilities between disparate public safety entities. The implementation included:

- Licensed spectrum from Houston Public Media Television (KUHT-TV)
- Commercial cellular leased by the City of Houston
- Public Safety LTE (Band Class 14) provided by Harris County Communications
- Live video streaming applications on mobile devices
- Datacasting end users were expanded (from the end users during the NCAA/Final Four events), and included users across multiple agencies and locations (e.g., City of Houston, Houston Police Department, Houston Fire Department, George R. Brown Convention Center).

Datacasting video feeds were available from a number of sources and distributed to a number of entities. Datacasting provided an interoperable capability for these organizations to have joint situational awareness even if they used different video viewing platforms and cameras. Datacasting made it possible for one agency's video feeds to be broadcasted to other agencies, and for those same views to be available to end users in the field. All cameras currently integrated into the city's PSVN system were available. Two independent video networks were established (and connected using the VidSys software) in the EOC. Transmitted content was managed using the Incident One Dashboard and by leveraging the auto designating capabilities of the system. Designated EOC staff were the primary datacasting operator(s) responsible for selecting and datacasting/transmitting/broadcasting video streams to pre-designated groups of end-users including HFD personnel, HPD personnel, and GRB command post personnel.

Video assets not available via the PSVN were available to datacasting users through another computer connected through the datacasting FlexStream-IO transcoder in the EOC. Other video sources included mobile phones of HFD and HPD officers in the field. These field units could transmit live streaming video through their cellular devices to the dashboard and have it broadcasted.

3.7 Key Stakeholders

The coordination of the efforts surrounding video network installation at Discovery Green Park included a number of stakeholders (Table 3). Coordination was directed through City of Houston Office of Public Safety and Homeland Security.

Table 3: Super Bowl Live Video Camera Solution - Stakeholders

Name	Entity	Role
Dennis Storemski, Director	City of Houston Office of Public Safety and Homeland Security	Executive Committee
Chris Newport, Executive Vice President	Houston Super Bowl Host Committee	Executive Committee
Jack C. Hanagriff	City of Houston Office of Public Safety and Homeland Security	Project Manager
Maurice Singleton	VidSys Inc.	Lead Quality Engineer; oversight and quality assurance
Tom Sorley		Deputy Director IT Public Safety
Steve Surfaro	Axis Cameras	Solution Architect; design and implementation strategy
Shaun Castillo	PrefTech	Solution Architect; design and implementation strategy; Technology Installation and Configuration Support
Christopher Windham	Verizon Wireless	Solution Architect; design and implementation strategy
Todd Holloman	Houston Host Committee	Site Logistics and Coordination
Paul Cannings	RPH	Site Logistics and Coordination
Eric Cummings	RPH	Site Logistics and Coordination
Tim Smith	Houston First	Site Logistics and Coordination
Miguel Macias	Houston First	Site Logistics and Coordination
Dee Boyd	Axis Cameras	Technology Installation and Configuration Support
Curtis Martin	City of Houston-PWE	Technology Installation and Configuration Support
Ashley Gonzalez	City of Houston-IT	Communication Liaison; Data Transport/Backhaul
Sandra Loughridge	Verizon Wireless	Communication Liaison; Data Transport/Backhaul
Larry Ewert	Verizon Wireless	Communication Liaison; Data Transport/Backhaul
N/A	Houston Police Department	Key User
N/A	Houston Fire Department	Key User
N/A	Houston EOC	Key User

3.8 Timeline & Milestones

The Super Bowl Live Discovery Green video communications effort was executed in three phases as described below:

- **Phase I**: Make use of existing infrastructure by installing ready devices on available poles or structures, and complete installation prior to the 2016 Christmas holidays. This allowed for initial system tests using crowd activity within Discovery Green leading up to the 2017 Super Bowl.
- **Phase II**: Add additional devices in needed spaces in conjunction with the construction of the Super Bowl Live Zone.
- **Phase III**: Removal of equipment from Discovery Green in conjunction of the dismantling of the Super Bowl Live Zone.

Table 4 shows the timeline for these preparations for Super Bowl Live.

Table 4: Super Bowl Live Video Communications Project

Date	Events/Milestones
September 2016	Concept Introduction
October 2016	Planning Meeting
October 2016	Hotel Roof Assessment (Four Seasons) by Houston Video Tech. Team
October 2016	Discovery Green Site Walk/Visit (Camera Location Planning)
November 2016	Final Camera Design and Layout
January 2017	Phase I Installation
January 2017	System Testing
January 2017	Phase II Complete
February 2017	Phase III Complete

4 Super Bowl Video Solution Observations and Outcomes

4.1 Temporary Video Network at Discovery Green Park

With significant pre-event coordination by City of Houston officials and Super Bowl Host Committee members, a private-public entity partnership was responsible for identifying requirements, obtaining hardware (including more than two dozen cameras), and installing equipment in order to facilitate a public safety video network for use during Super Bowl Live events at Discovery Green Park. This system deployment was successful in providing both novel and redundant communications capabilities for the public safety community leading up to, during, and after Super Bowl events. Some of the installed equipment remains in use today.

The installed video network resulted in a significant improvement in public safety situational awareness in Discovery Green Park not because of a lack a previously existing city infrastructure, but because large scale events often exceed the operational capabilities of existing systems. Stages, gates, and other physical structures added for such events may obstruct existing camera views. The large crowds often saturate existing cellular networks. The presence of multiple public safety entities increases the need for joint situational awareness. The installed video system improved the ability for public safety end users to

maintain situational awareness while using redundant communication paths including Band Class 14, fiber, and datacasting.

While coordination of these efforts among several agencies and companies was required, the video system installation was relatively quick (except for fiber installation, which was beneficial but not required for the system), with installation and testing occurring in approximately 48 hours. Because of the operational advantages of the video network solution and timely system installation, an approach such as this one used for Super Bowl LI in Houston would be a useful model for other large scale events (especially event in dense urban cities), which require a number of special considerations (e.g., cellular network congestion and management, limited video sightlines, public safety interoperability, etc.) for video camera use and installation.

4.2 Datacasting

Datacasting was used during Super Bowl LI by public safety entities including the HFD and HPD. Notably, the capability to use city commercial and Band Class 14 cellular phones to send live video streams to command centers for viewing and redistribution was utilized widely. End users noted the ease of use of the associated GoCoder application and recommended its further dissemination among their organizations in conjunction with expanded end user training.

Another important result was the testing to determine how many "typical" datacast video streams could be simultaneously transmitted by datacasting before bandwidth consumption degraded reception. Tests started with 1 Mbps and new streams were added until video quality was noticeably degraded. Current Public Television broadcasting allows for 1 Mbps, but these stations have agreed to increase the rate during NSSE and other significant events. At 1.5 Mbps, noticeable degradation did not appear until six streams. At 2.0 Mbps, seven video streams were transmitted with minimal degradation.

During events leading up to the Super Bowl (including the Houston Chevron Marathon described in Appendix C), the HPD expressed interest in piloting the use of datacasting more broadly within their organization, which resulted in the installation of the datacasting capability in the RTCC and in several patrol cars. While system expansion and training will continue with the HFD, a formal pilot with HPD was established and will continue in earnest after the Super Bowl.

As part of the operational testing, DHS S&T interviewed a number of first responders during and after the January 2017 Houston Marathon. These interviews were shared with JHU/APL. Based upon their feedback, JHU/APL was able to make the following observations:

1. First responders have a desire for more data to support their mission. They are aware that there are far more data available, but they currently do not have access to that data. For example, a representative of HFD noted that access to information regarding building plans and toxic hazards located at a site would be helpful to firefighters. It was felt that datacasting, with its ability to transmit content over the air, could greatly assist firefighters.
2. Emergency Management personnel indicated that there was great value in geo-location. Tracking personnel from over two dozen agencies across an area of responsibility the size of Houston is a challenge. Automated geo-location and enhanced video access could greatly enhance situational awareness.
3. Video has great value. There is an imprecision in words over audio; having video can provide information not readily conveyed in verbal descriptions. Decision makers viewing video can have greater confidence in their decisions; video helps minimize ambiguity.
4. With increased data transmission, there will be greater need to organize data at command centers. Specifically, call center operators will need to be able to readily access relevant data and transmit it to first responders. First responders do not have time to search for the data they need. It needs to be organized so that a call center operator can push it to officers in the field.

End user feedback reinforced the conclusion that first responders would like to have increased access to data and video. Because large data files and video can require large expenditures in capacity in a cellular based network, especially if they are widely disseminated, datacasting's efficient scalability has substantial potential benefit. Finally, end user comments reinforced the conclusion that integration issues will require increased attention in the future. Regardless of the communications medium – datacasting, dedicated Band 14, commercial cellular – systems need to be integrated to enable rapid and easy access to relevant data.

4.3 Datacasting and Cellular Measurements during Super Bowl LI

In addition to the operational use of datacasting during the Super Bowl events (4 and 5 February), JHU/APL took the opportunity to perform a series of test measurements comparing datacasting availability with cellular network coverage.

During 4 and 5 February, a JHU/APL test team performed a series of measurements at various points across downtown Houston, in the vicinity of the Super Bowl Live event on Discovery Green, and outside NRG Park. The purpose of these measurements was to augment feedback from public safety officers equipped with datacasting receivers and to provide quantified data to enhance understanding of how limited bandwidth might affect a cellular network. It needs to be stressed that these measurements were not intended as an assessment of the capability provided by any particular commercial cellular carrier, and the results should not be treated as indicative of the quality of service provided by a carrier.

In preparation for the datacasting/cellular test, the test team created an account and loaded the IncidentOne software onto a laptop. An Ultra High Frequency (UHF)/Very High Frequency (VHF) antenna was connected to the laptop's Universal Serial Bus (USB) port via a Hauppauge WinTV-HVR-850 receiver. The IncidentOne software provides a capability to monitor the status of reception via datacasting. Figure 9 contains a screen capture of the status screen taken while the antenna and laptop were out of range of a datacasting signal. If the equipment had been receiving datacast packets from the local television station, the row displayed in red in Figure 9 would have been white and the values of the signal and quality would have ranged from 70 to 100. Similarly, if the software was receiving packets (even null packets), the row displayed in yellow would have been white and the last packet would display a value of <1 second. Even with nearly perfect datacasting reception, there would be lost and recovered packets, but the number of such packets would rise only slowly.

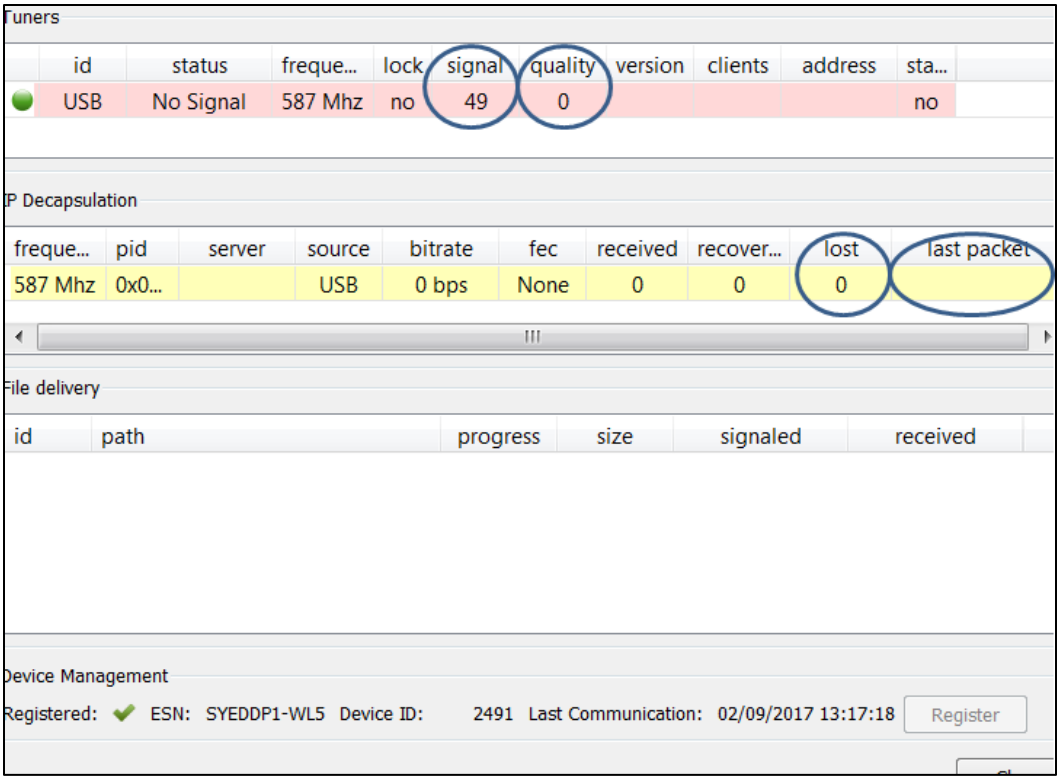

Figure 9: Datacasting Status Screen

The test team went to various points around the Houston downtown area holding the antenna and observing the status screen on the laptop. A dry run was performed Friday afternoon of Super Bowl weekend, and an extensive attempt to measure reception was executed on Saturday afternoon. Only one test was performed using datacasting because reception was not expected to vary as a result of changing levels of traffic.

The primary purpose of the measurements was to test the hypothesis that at large events where cellular bandwidth congestion would be expected, cellular based technologies may have trouble transmitting and receiving video or other large data content. Previous analysis performed by JHU/APL has suggested that datacasting has the potential to enable download of data content and real-time video during times of congestion on cellular networks. It was hoped that these tests would provide an empirical test of datacasting data delivery at times and in locations where when cellular download capacity was diminished.

As an official sponsor for events in Houston during Super Bowl week, Verizon substantially augmented its existing network infrastructure to support security and customer needs. Therefore, the cell phone used in these tests operated on a different network carrier in order to provide a more realistic comparison. However, it is not known whether this other cellular carrier augmented its capacity to support its subscribers during Super Bowl LI.

Detailed results of this cellular service testing are provided in Appendix F. The data recorded by the test team supported the premise that datacasting can provide an effective redundant path during high congestion conditions when cellular download rates are greatly reduced due to demand. These test results corroborated anecdotal evidence from the public safety community.

5 Conclusions

Under the direction of the DHS S&T Directorate, JHU/APL has been tasked with performing a series of technical experiments for testing and evaluating an enhanced integrated telecommunications architecture for use by public safety during mass gathering public events, especially those designated National Special Security Events (NSSE). Each of these technical experiments expanded on previous ones by including an evolving communications technology architecture and a broader user community. This report describes the most recent technical experiment where this enhanced public safety communications architecture was used to support security operations during Super Bowl LI, which was an NSSE that took place in Houston, Texas, in February 2017.

In support of security operations associated with the Super Bowl, the City of Houston Office of Public Safety and Homeland Security, Harris County Central Technology Services, and DHS S&T First Responders Group / Office for Interoperability and Compatibility have worked together with private industry to augment the public safety communications for the City of Houston and Harris County. As a result of these coordinated efforts, the City of Houston and Harris County were able to deploy a public safety communications architecture during the Super Bowl that:

- Contained redundant communications pathways using commercial cellular-based, dedicated Band 14, and over-the-air datacasting to ensure resilient reliable communications to and among first responders.
- Provided robust data-driven (as opposed to traditional voice-centric) communications to support collaboration, geo-location, and video-streaming capabilities.

Early feedback from end-users indicates that, although the data-driven architecture (which made heavy use of applications for dissemination of data, including live video streams) was new and different, the officers were generally pleased with the changes and felt they contributed significantly to improved situational awareness. At one point, the ability to stream live video was especially helpful in determining the outcome of a vehicle crash, directing the appropriate resources to the accident site, and determining the impact on associated traffic congestion. Other incidents involving the use of handheld mobile phone video included a small fire that was quickly extinguished and a suspicious package that was quickly identified. Operations during the Super Bowl confirmed the desirability of video data to support public safety. The following summarizes the end user feedback received to date:

- There is a desire for having greater access to more of the available data, including building plans, hazardous material locations, and first responder geo-location.
- Enhanced video access can provide information not readily conveyed verbally by LMR. Decision makers have greater confidence in their decisions when they can view video of the situation.
- With increased data available for transmission, first responders do not have time to search for the data they need. Call center operators will need to have ready access to relevant data, the ability to organize and prioritize these data, and the ability to push the relevant data to officers in the field.

Because no significant public safety communications failures occurred, the Super Bowl LI tests were unable to demonstrate the benefits of communications redundancy using datacasting during such failures. However, measurements taken by JHU/APL corroborated the premise that, during congested conditions on commercial networks, datacasting could provide a valuable alternative path for downlink communications. Measurement made during Super Bowl weekend indicated that the ability to download data via a cellular network was negatively impacted by congestion and that this network access degradation was greater on the periphery of the events than within the event venues. Therefore, it is important to note that, while carrier enhancements to network capacity at key venues may largely alleviate congestion, the benefits from these upgrades may not necessarily extend outside the targeted venue. On the periphery of these venues, congestion could still remain high depending on the carrier's

enhancement priorities. During these technical exercises, no degradation in communications that used datacasting was found in and around venues. As first responders may also have to operate in surrounding areas outside the event venues, datacasting would thus be especially useful. These results were based upon limited testing – for example, there was no opportunity to evaluate whether access to Band 14 would change the results. Additional testing is recommended to confirm these results. However, the technical experiment performed during Super Bowl LI indicates that datacasting could be a valuable means for achieving redundancy and more efficient delivery of video and other data in support of mass events, including NSSE.

6 References

(a) Department of Homeland Security Science and Technology First Responders Group "Video Datacasting: Houston Pilot After Action Report" October 2015. (https://www.dhs.gov/sites/default/files/publications/Houston%20Datacasting%20Pilot%20After%20Action%20Report.pdf)

(b) Department of Homeland Security Science and Technology First Responders Group "Datacasting: Houston Integration Pilot After Action Report" July 2016. (https://www.dhs.gov/sites/default/files/publications/Houston-Datacasting-Integration-Pilot-After-Action%20Report-v7-08122016-508_0.pdf)

(c) Department of Homeland Security Science and Technology First Responders Group "Datacasting: NCAA Deployment in Houston Report" July 2016. (https://www.dhs.gov/sites/default/files/publications/Datacasting-Use-at-NCAA-Houston-v5-08012016508C_0.pdf)

(d) Department of Homeland Security Science and Technology First Responders Group "Snapshot: Live Video Streaming Via Smartphone, Brought to you by Datacasting" June 8, 2016. (https://www.dhs.gov/science-and-technology/news/2016/06/08/live-video-streaming-smartphone-brought-you-datacasting)

(e) The Johns Hopkins University Applied Physics Laboratory Report AOS-16-0920, "Resilient Communications Project: Communications Capabilities Deployment Event – Freedom Over Texas." 17 August 2016.

APPENDIX A: Abbreviations and Acronyms

Acronym	Definition
ACPs	access control points
ATSC	Advanced Television Systems Committee
CCTV	closed circuit television
CJIS	Criminal Justice Information Services
COW	cell on wheels
CPU	central processing unit
CTS	Harris County Central Technology Services
DHS S&T FRG	US Department of Homeland Security (DHS) Science and Technology (S&T) Directorate's First Responders Group (FRG)
DS7	Digital Sandbox 7
EOC	Emergency Operations Center (City of Houston)
GRB	The George R. Brown Convention Center
HD	high definition (video)
HFD	Houston Fire Department
HPD	Houston Police Department
JHU/APL	Johns Hopkins University Applied Physics Laboratory
LTE	long-term evolution
LMR	land mobile radio
NCAA	National Collegiate Athletic Association
NFL	National Football League
NSSE	National Special Security Event
PSVN	public safety video network
PTZ	pan tilt zoom (cameras)
RTCC	Real-Time Crime Center (Houston Police Department)
SB	Super Bowl
SD	standard definition (video)
UHF	ultra high frequency
USB	universal serial bus
VHF	very high frequency
VMS	video management system

APPENDIX B: Technical Details of Datacasting

Television stations transmit aggregate broadcast streams at a constant 19.39 Mbps data rate. Various programs are multiplexed into the aggregate stream. Often television content will not consume the full data rate, or content can be set to use less than the full data rate. When this is the case, null packets are used to fill the unused data rate (see Figure B1). In datacasting, the null packets are replaced with datacasting information that can be received and interpreted by registered recipients with the required equipment.

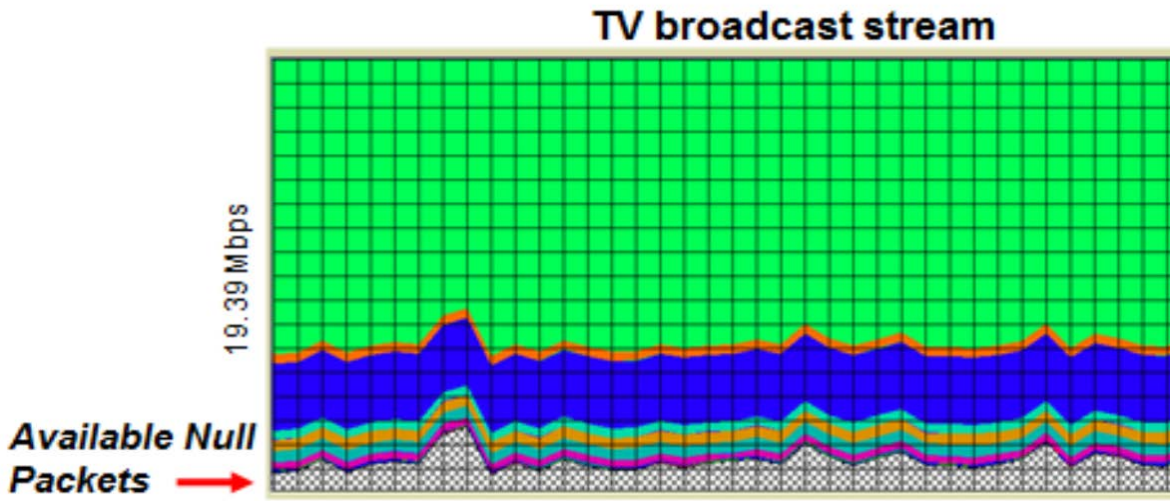

Figure B1: Digital TV Broadcast

There are three distinct aspects to the datacasting system: (1) information collection and processing, (2) transmission processing, and (3) reception processing (see Figure B2). Optionally, datacasting may be integrated into other systems to create a return path for two-way communication and services. In the prototype system implemented in Houston, information collection and processing, including decisions as to what information to send and to whom, were performed at the University of Houston Office of Emergency Management (OEM). Transmission was performed at the Public Broadcast System (PBS) television station KUHT owned and operated by Houston Public Media. Reception equipment was implemented in laptops belonging to the various public safety agencies participating in the demonstration.

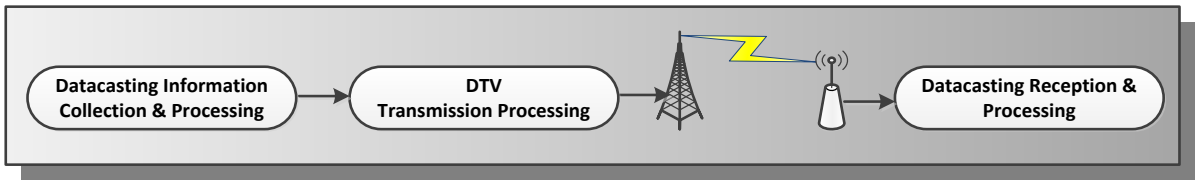

Figure B2: Components of a Datacasting System

Similar to satellite television providers (such as DirectTV), more than one TV program may be included (i.e., "multiplexed") into one digital television transport stream. Datacasting is an additional program stream in this broadcast channel, but it is not referenced in the Program and System Information Protocol (PSIP), so it does not appear as a "channel" to television sets.

Transport streams are based upon Moving Pictures Experts Group (MPEG)-2 standards. Datacasting information may be embedded within the DTV signal, as represented in Figure B3. In this figure, each packet of the broadcast stream including the datacasting packet consists of a 4-byte header and 184 bytes of information.

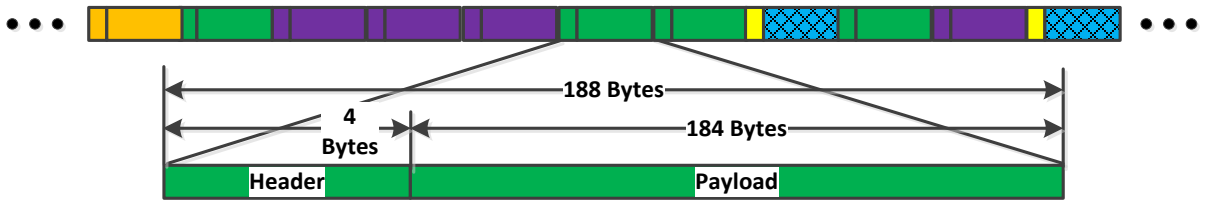

Figure B3: Datacasting within a DTV Stream

The header consists of 32 bits, including a 13-bit Packet Identifier (PID{ XE "PID:Packet Identifier" }), as shown in Figure B4.

Sync	Error Indicator	Payload Unit Start Indicator	Transport Priority	PID	Transport Scrambling Control	Adaptation Field Control	Continuity Counter
8 Bits	1 Bit	1 Bit	1 Bit	13 Bits	2 Bits	2 Bits	4 Bits

Figure B4: DTV Broadcast Stream Header Format

Figure B5 illustrates the DTV transport components. The transport consists of services (i.e., television channels), which are made up of events (i.e., television programs) that each has their own elementary service streams (e.g., packetized MPEG 2 streams consisting of video, audio, metadata, and service information).

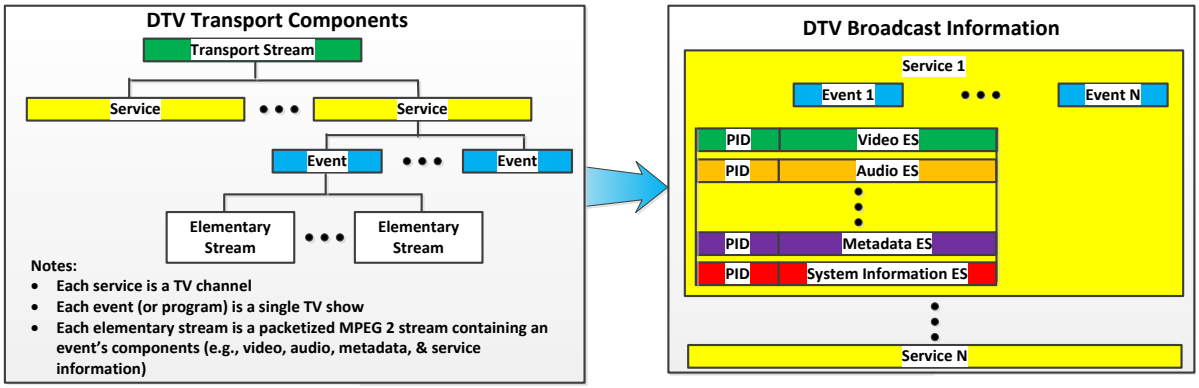

Figure B5: DTV Transport Components

The elementary service System Information contains various tables including:

- Program Association
- Program Map
- Network Information
- Service Description
- Event Information
- Conditional Access
- Bouquet Association
- Time and Date
- Time Offset

System Information tables include PID assignments to elementary streams, events, and services. System Information packets are assigned pre-determined Packet Identifiers (PIDs).

Figure B6 contains a representation of the Datacasting Transport information, which is different than that of the regular television transport. Datacasting does not use the System Information tables and PIDs are pre-assigned to datacasting. PIDs are not included in the System Information tables to prevent DTV receivers from searching for a "ghost" service, event, or elementary stream. Datacasting uses "Access Control" to identify PID Assignments, Receiver Assignments, Receiver Group Assignments, Protocol Assignments (e.g., video, file, and messaging assigned to individual and/or group receivers), and key list assignments (for encryption/decryption). Access Control is transmitted on a regular periodic interval.

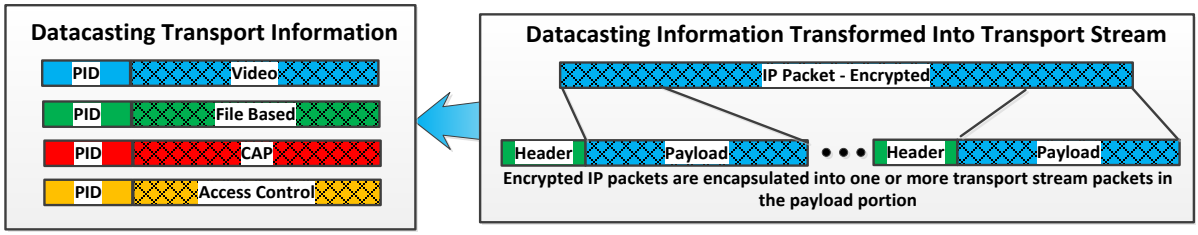

Figure B6: Datacasting Transport Stream

Datacasting Information Collection and Processing

In general, the datacasting system is configured to incorporate four types of data (Figure B6) into the datacasting transport stream. These four data types include the following:

1) Real-Time Streamed Data (blue in Figures B6 & B7). Typically, the streamed data may consist of video information such as from a Closed-Circuit Television (CCTV**{** XE "CCTV:Closed-Circuit Television" **}**) system. Other streamed data such as audio, weather information, and news broadcasts can also be incorporated.
2) File-Based Information (green in Figures B6 & B7). This information includes documents, images, and audio and video clips. It can include other types of digital information such as software. Forward error correction (FEC) and carouselling are used to assure all packets are received, even in degraded reception environments. Recall that a carousel is defined by ATSC (www.ATSC.org) as a group of objects transmitted repeatedly from a particular service provider for a specific purpose or service.
3) Message Based Information (red in Figures B6 & B7). Generally, the messages are Common Alerting Protocol (CAP**{** XE "CAP:Common Alerting Protocol" **}**) compliant messaging, allowing messages and notifications to be processed by any CAP compliant alerting platform.
4) Access Control Information (yellow in Figures B6 & B7). File-based data are used to control registration and access. This information includes receiver registration, receiver group assignments, protocol assignments, key list assignments, and PID assignments.

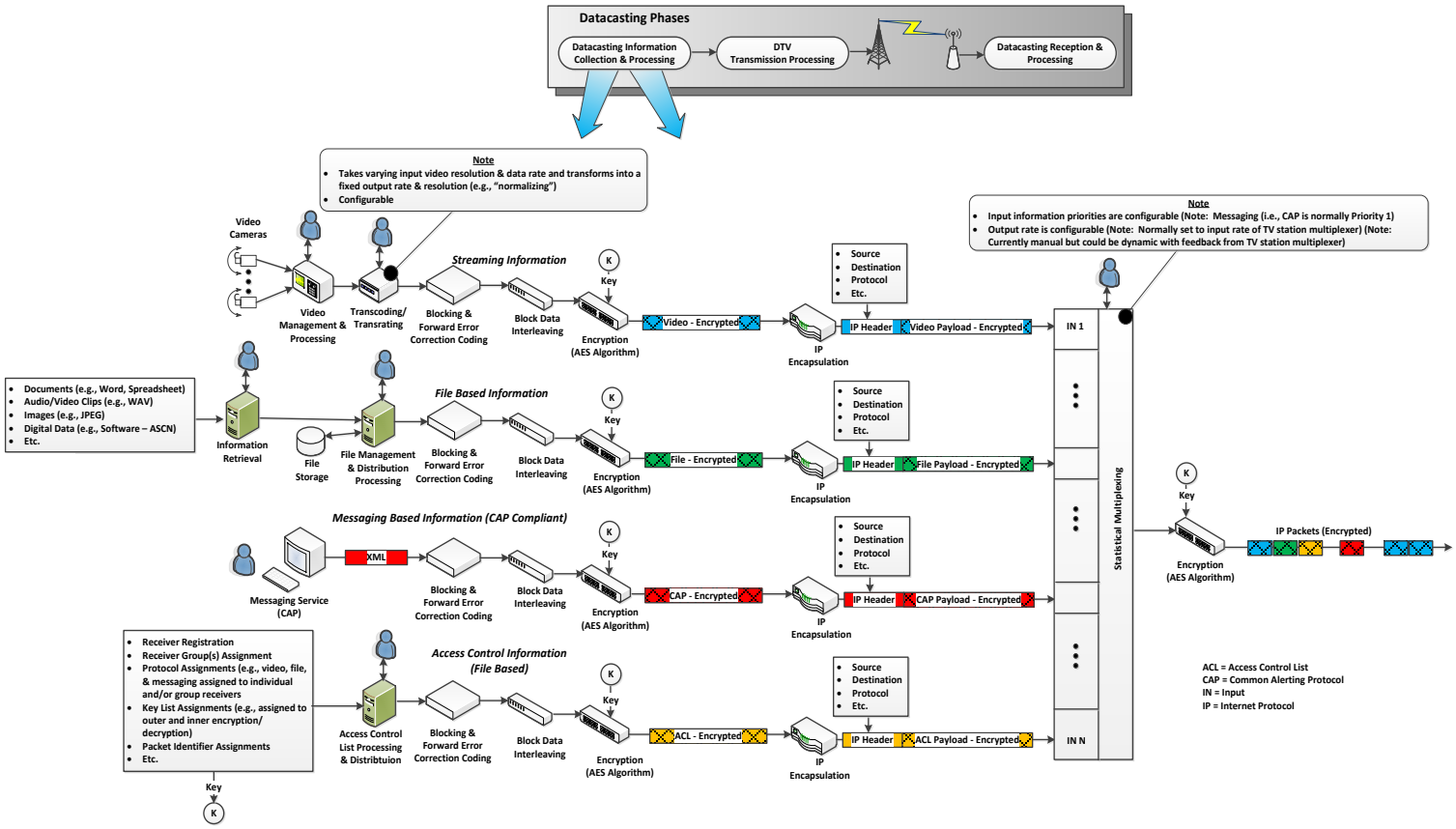

Figure B7: Datacasting Information Collection and Processing

Some portions of the data preparation process are common for all information types. Data are blocked and forward-error correction[3] is applied. Forward Error Correction is an encoding technique that protects the transmission and reception integrity of the data. It is used to detect and correct "bit-errors," technical problems that cause an occasional bit in a data stream to be misinterpreted. Provided the rate of errors in a data stream remains below a threshold, the Forward Error Correction Code can correct errors in the data stream. Forward Error Correction is a ubiquitous technique; it has no encryption value. The block data are interleaved and encrypted. Encrypted data are encapsulated using IP encapsulation into the MPEG transport packets. Source, destination, and protocol data are packaged into the header. The datacasting packets are multiplexed to form a stream that is further encrypted using AES-256.

Transmission Processing

Transmission processing (see Figure B8) consists of merging (multiplexing) the datacasting data stream with the television programming stream(s), as depicted in Figure B9. Prior to the merging, the datacasting stream is processed into DTV transport packets and each transport packet is assigned a PID.

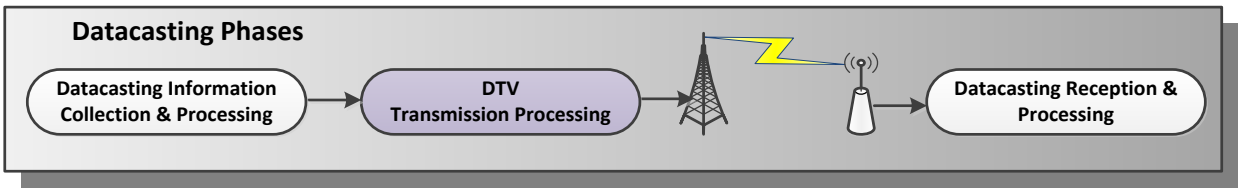

Figure B8: Transmission Processing

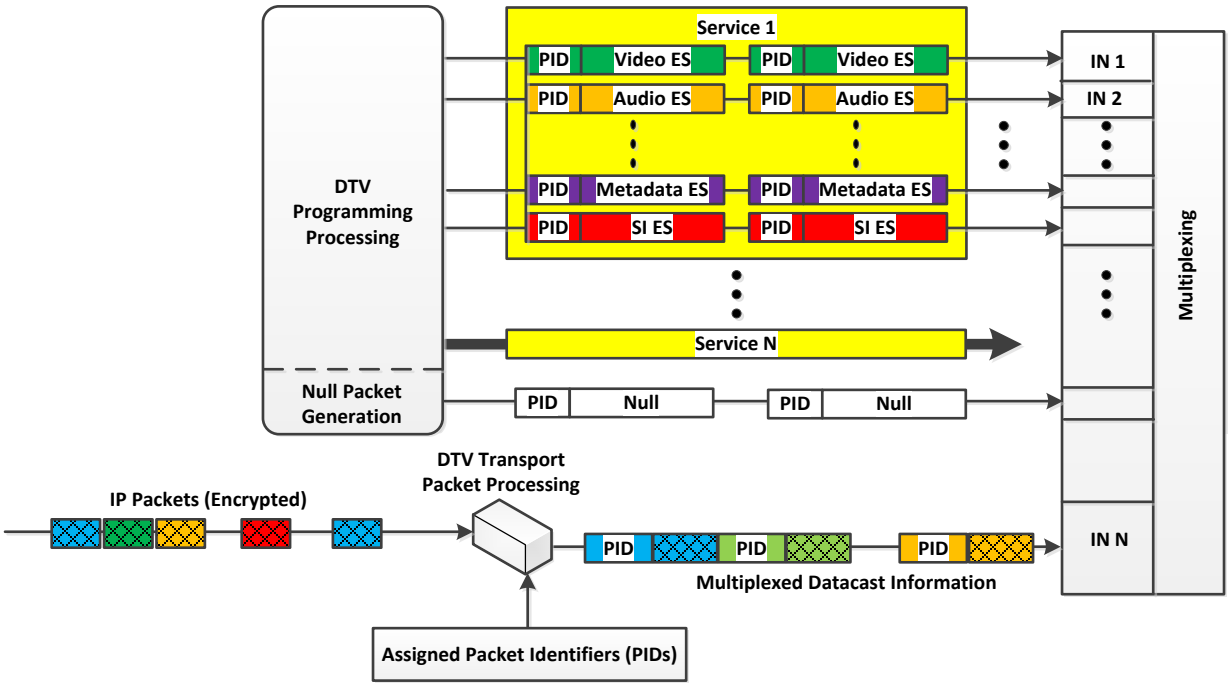

Figure B9: Multiplexing Datacasting and Television Streams

The overall output rate of the resulting merged stream (including datacasting and programming information) is 19.39 Mbps. Bit rate allocations are configurable. However, under normal conditions, there will be approximately 1-2 Mbps available for datacasting. This bit rate can be increased should conditions warrant it. Maximum bit rate is currently set manually. In the future, it may be possible to

3

enter the information electronically into the information collection statistical multiplexor, which would enable the system to dynamically re-allocate the bit rate. Null packets are required to maintain a constant 19.39 Mbps bit rate.

Figure B10 depicts the functions performed on the multiplexed signal through transmission. The signal is modulated using 8 level vestigial sideband modulation (8-VSB) and transmitted.

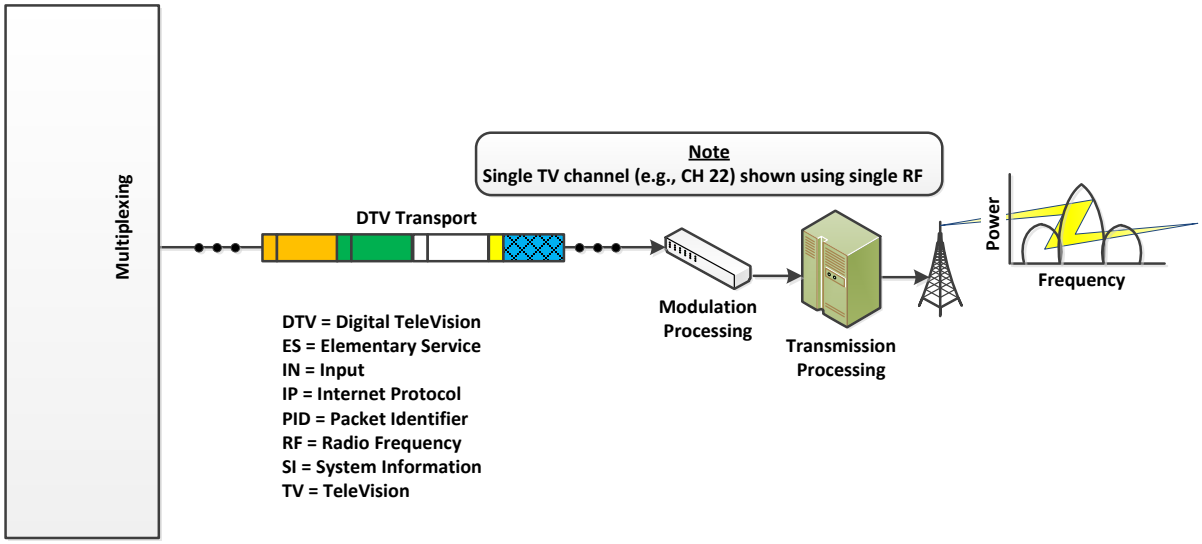

Figure B10: Transmission of Multiplexed Data

Datacasting Reception and Processing

Datacasting reception (Figure B11) begins with reception of the signal by a receiver connected to a computing device (not a television set). The receiver can be a USB "dongle" or Linux based appliance. Any UHF or VHF antenna will capture the signal. However, only devices with the required software, decryption, and registration will actually be able to convert the signal into useful information. Upon receipt of a signal, the datacasting system demodulates the signal and identifies the packets directed to the device according to the assigned PIDs. A device can be designated as the unique registered recipient or as part of a group registration.

When a device is authorized to receive data, the encrypted IP packets are decrypted for processing by the appropriate application software in the device. Figure B12 depicts the process.

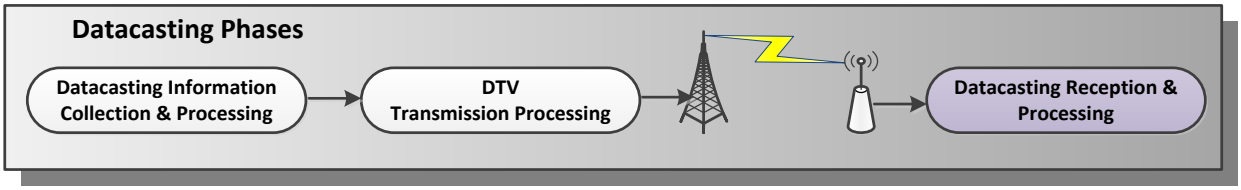

Figure B11: Datacasting Reception and Processing

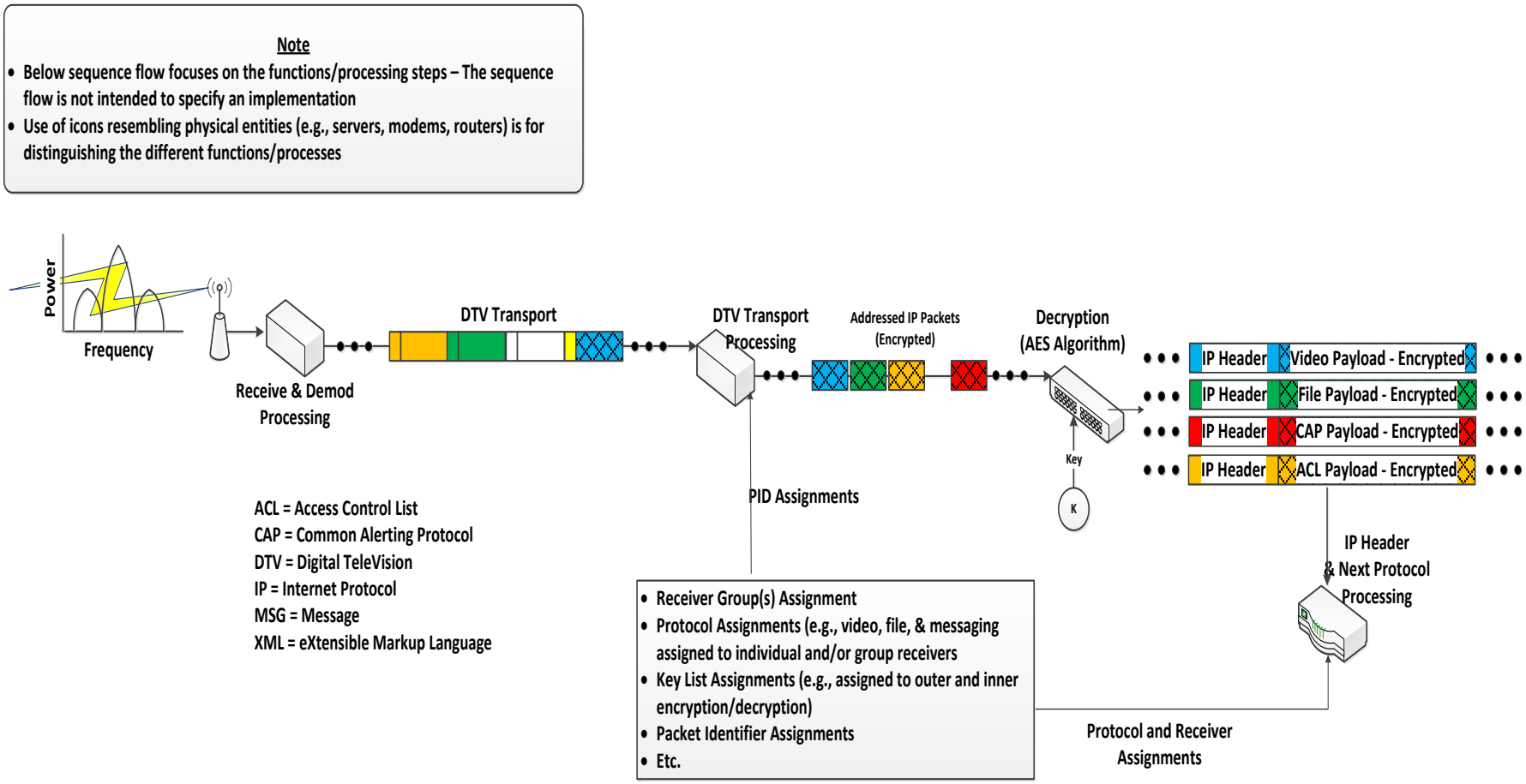

Figure B12: Datacasting Receipt

Finally, IP packets are processed according to type (streamed data, files, messages, and access control) as shown in Figure B13. The further processing of data type is contingent on the access control list that identifies the encryption keys and receiver assignments to be used for each data type processed by this receiver.

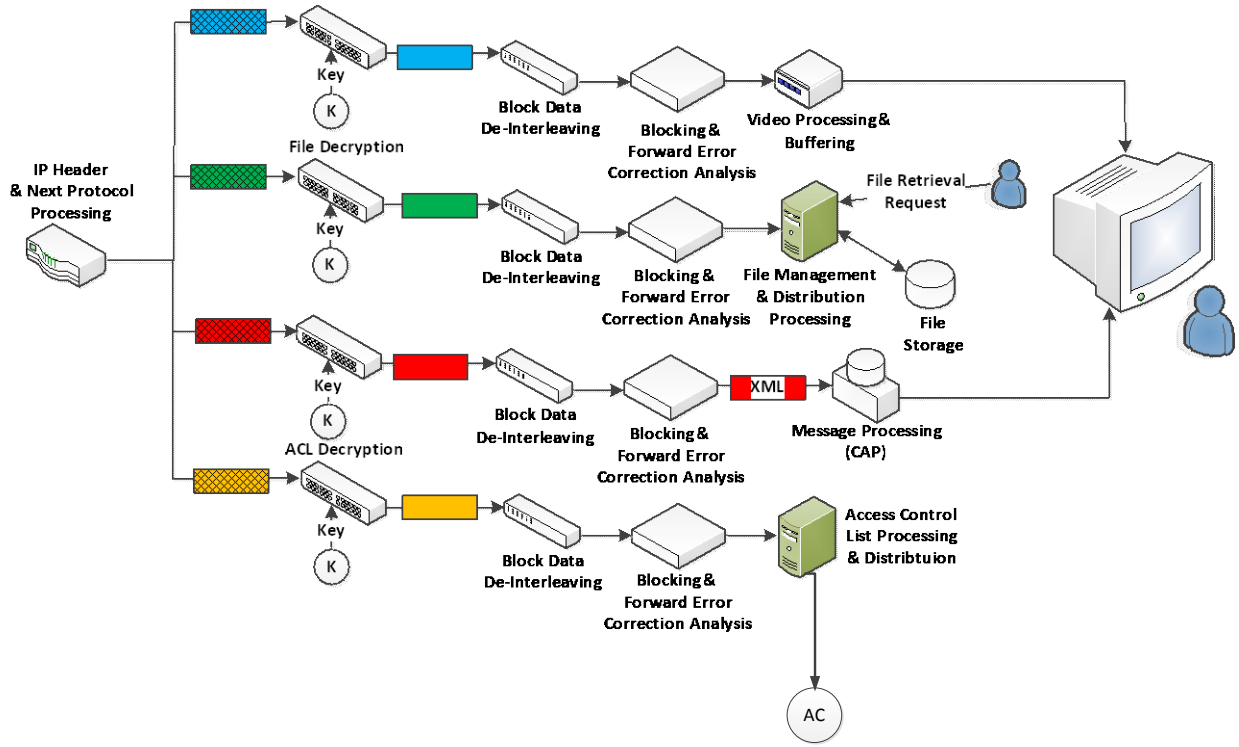

Figure B13: Processing Received Datacasting Information

APPENDIX C: Notes from 13 January 2017 Meeting with City of Houston, HPD, and HFD

The JHU/APL test team had the opportunity to participate in meetings with representatives of HPD, HFD and the City of Houston in which end-user feedback was acquired. There exists considerable enthusiasm within the Houston public safety community for datacasting and the capabilities it brings, and there is a strong desire to expand its role within the overarching public safety architecture. Specific points of discussion included the following:

- There was discussion regarding relationships between datacasting and FirstNet. It was noted that some of the proposals to FirstNet contain datacasting as a component. A key objective of operational tests in Houston is to assess how a datacasting capability could be integrated into a FirstNet compliant network such as Harris County's Band 14 LTE network.
- HPD expressed significant interest in disseminating helicopter video. HPD also inquired about dissemination of video from vehicle dash cameras. Datacasting can facilitate wider dissemination of these video feeds after they reach the command post. The Houston participants who have used datacasting video provided positive feedback regarding the quality of this video. HFD described some examples of the usefulness of datacasting video. In particular, HFD described how datacasting video provided a more useful description of smoke rising from a fire than could be provided via voice.

- HPD is planning to expand its use of datacasting, specifically, the connectivity between existing databases. SpectraRep has already initiated discussions with HPD on such an expanded capability. Eventually, the HPD would like this to include integration of Houston Integrated School District video.

The meetings and feedback from HPD resulted in the expansion of datacasting to include a HPD datacasting pilot system which began with the installation of datacasting equipment in the HPD Real-Time Crime Center (RTCC) and in select patrol cars and will continue with expanded equipment/capability deployment, end user training, operational testing, and end user feedback.

APPENDIX D: Results of Super Bowl (SB) Video Solutions Operational Test at the January 2017 Houston Chevron Marathon

Introduction

The Johns Hopkins University Applied Physics Laboratory (JHU/APL), under the direction of the Department of Homeland Security Science and Technology Directorate (DHS S&T), First Responders Group, Office for Interoperability and Compatibility, supports field exercises for operational testing and evaluation of public safety communications systems that integrate disparate technologies, including datacasting and Long Term Evolution (LTE) cellular. The Datacasting Task is a DHS S&T project aimed at providing local, state, and federal law enforcement with a means for using locally acquired video (e.g., CCTV, mobile) data to first responders to enhance their situational awareness, especially for those who are critical event first responders. It is also exploring techniques for increasing the resiliency of existing and emerging communications networks. Datacasting uses a portion of the transmission bandwidth of Public TV stations to send video and other data in an encrypted and secure way to these first responders. DHS S&T tasked JHU/APL to conduct a series of operational tests and evaluations using different scenarios to help determine what components are needed, useful, required, and recommended specific to local, state, and federal law enforcement requirements. Datacasting is envisioned as part of an integrated communications network (e.g., FirstNet).

This report describes datacasting systems integration testing performed during the January 2017 Houston Chevron Marathon. The purpose was to assist the City of Houston and Harris County emergency response agencies in configuring communications and evaluating its readiness to support a larger operational test during the 2017 Super Bowl. Objectives specific to the Marathon focused on testing and evaluating the readiness of the various components within the telecommunications architecture to support operations and operational communications. The objective was to verify each of the potential datacasting communications pathways that might be exercised during the Super Bowl and its associated activities.

As the City of Houston and Harris County provided public safety coverage of the 2017 Houston Chevron Marathon, video and data content were successfully sent to the Houston Public TV station for transmission by datacasting. These datacasts were successfully received by public safety personnel for the City of Houston and Harris County. Public safety users expressed the opinion that the video data quality received via datacasting was excellent. There appeared to be some compatibility issues associated with the use of 32-bit vs. 64-bit operating systems, and there are plans to resolve this issue prior to operational use at the Super Bowl. Also, it was found that using Port 80 as input to the SpectraRep software dashboard was a problem due to Houston security software causing it to time out prematurely; however, this issue was resolved by using a different port. In addition, there was some concern about datacasting congestion if KUHT TV transmission were limited to 1 Mbps, although it is expected that this will be raised to 1.5 Mbps for operations during the Super Bowl.

Background
Representatives of the Johns Hopkins University Applied Physics Laboratory (JHU/APL) and their subcontractor, SpectraRep, tested elements of an integrated public service telecommunications architecture at the Chevron Houston Marathon on 15 January 2017 in downtown Houston, Texas. The purpose of this test was to assist the City of Houston and Harris County Emergency Response agencies in configuring their equipment and evaluating its readiness to support a larger operational test during the 2017 Super Bowl weekend activities.

Objectives
JHU/APL has performed analyses indicating that an integrated architecture incorporating datacasting to provide a redundant communications path has the potential to provide the following benefits:

- Datacasting has the potential to provide first responders with a communications capability that may be more resistant to extreme weather than existing cellular based communications. Although it is not possible to simulate extreme weather conditions in an operational environment, there is empirical evidence that, during extreme weather events, cellular systems are vulnerable to power losses resulting in extended loss of service while most television transmissions have been relatively unaffected.
- Analyses have also indicated that cellular based systems are subject to loss of service due to bandwidth congestion during public emergencies, such as the September 11 (2001) terrorist attacks, the 2013 Boston Marathon bombing, and immediately following earthquakes. A primary test objective is to verify whether datacasting can provide coverage when cellular system bandwidths are saturated by congestion.
- Analyses have also indicated that datacasting can provide rapidly deployable interoperability to disparate emergency response agencies. JHU/APL and DHS S&T first tested this capability during a July 2015 test in Houston. Further re-creating conditions in which organizations with disparate telecommunications systems inter-operate to support additional data collection is a test objective.
- Datacasting's efficient one-to-many transmission capability has the potential to relieve demand on public safety networks. Although there are no explicit plans to test this during the Super Bowl, the test team may, by serendipity, capture data to verify this.
- Finally, JHU/APL will use this exercise to collect data and observations regarding the operational needs of the emergency response community and to refine methodologies for measuring video quality and data utility.

Venues
Super Bowl LI will be played at NRG Stadium in Houston on Sunday 5 February 2017; however, large public events will be staged at venues across the city for most of the week[4]. In addition to NRG Park, large-scale events are planned for Discovery Green and the George R. Brown Convention Center, the Galleria, and at Club Nomadic, a collapsible three-story travelling nightclub to be erected at Sawyer Yards. The communications architecture employed during the Super Bowl will need to provide public safety officers situational awareness regarding events all across the city. Figure 1 in the main text provides the locations of some of the critical venues.

To support public safety during events, the City of Houston has deployed an integrated telecommunications architecture with critical components that include the following:

- A suite of surveillance cameras at critical sites, including NRG Park, the Galleria, and Discovery Park, integrated via the city's VidSys software and Verizon Cloud Services.
- The nation's first FirstNet-compliant Band 14 LTE system for public safety.

[4] http://www.khou.com/sports/nfl/superbowl/party-guide-super-bowl-51-parties-and-events/380367901

- SpectraRep's IncidentOne system, which provides users efficient secure one-to-many video and data content dissemination via both LTE and datacasting.

Test Objectives – Chevron Houston Marathon, 12-15 January 2017

Objectives specific to JHU/APL testing from 12 -15 January focused on evaluating the readiness of the various components within the telecommunications architecture. The overarching goal of this event is to ensure test readiness to support operations and operational communications during the Super Bowl and any associated activities, such as the number of large concerts to be staged around the city. The primary objective of JHU/APL testing during the Marathon was to verify each of the potential datacasting communications pathways that might be exercised during the Super Bowl. Figure 5 in the main body of this document contains a representation of the expected communications architecture to be supported. Additional datacasting receiver equipment may be installed between now and the Super Bowl and, as a result, these new transmission paths would then require testing. Critical pathways within this architecture include the following:

- Surveillance cameras at Discovery Park and around the George R. Brown Convention Center are connected to the Verizon Cloud (where they can be analyzed with Verizon video analytics).
- Surveillance cameras at NRG Park and the Galleria and other public safety cameras (e.g., traffic cameras) are connected to the City of Houston Public Safety Video Network.
- Operators within the Houston Emergency Center (HEC) can access video from cameras via the VidSys video management system.
- Public safety officers, police, and firefighters have voice and data communications via both commercial cellular service (Verizon) and the Harris County Band 14 LTE Network for Public Safety (AT&T). They also have Land Mobile Radio (LMR) voice capability.
- Officers at the HEC and Chief Cook of the Houston Fire Department (HFD) have the ability to push video and other data content to laptops hosting the IncidentOne software via the Internet; recipients can view the video using the IncidentOne dashboard.
- Officers at HEC and Chief Cook of the HFD have the ability to push video and other data content to laptops hosting the IncidentOne software and a dongle via datacasting; recipients can view the video using the IncidentOne dashboard.
- Approximately 25 Houston Police Department (HPD) and HFD mobile phones were configured to transmit video to the datacasting cloud for viewing on the IncidentOne dashboard.

Activities

The following efforts were accomplished during the four-day testing event (Figure D1):

- The test team verified datacasting reception within the NRG Center. A command center will be stood up in the NRG center in the same room that housed the control center following Hurricane Katrina. The test team measured the reception at various points in the room using the laptop and antenna that will be used to support datacasting reception during the Super Bowl.
- The test team successfully configured approximately eight tablet computers and 25 handheld communications devices – operating on commercial and Band 14 networks – to transmit data to the datacasting cloud. Wowza GoCoder applications were loaded onto each phone, and the test team verified that users could "push" video captured using the device camera to the datacasting dashboard via LTE. These devices were used by HFD firefighters, many of them patrolling the Marathon route on bicycle during the event. These devices are expected to see additional use during the Super Bowl. In addition, the test team held a training session with firefighters on 13 January.
- A member of the test team observed the 5-kilometer race held on 14 January from within the command center configured inside the convention center. Although none of the datacasting equipment was used – the majority of the public safety personnel trained to use the system at the

Marathon on Sunday were not due to work that Saturday – the opportunity to observe the race from the perspective of the police officers and firefighters providing security and public safety was invaluable and enabled the test team to make some additional accommodations to ensure successful testing during the Marathon. The remainder of the test team observed the race from the HEC.

- Members of the test team operated and collected data and observations related to the datacasting system during the Houston Marathon on Sunday 15 January 2017. Two members of the test team were situated in the HEC so they could operate the datacasting equipment and coordinate activities. One member of the test team remained at the back of the convention center operating datacasting equipment and collecting observations with HFD. The final member of the team accompanied City of Houston public safety officers and DHS S&T while collecting observations from the field and interviewing end users.

Figure D1: Course of Houston Marathon

Results

The following objectives were successfully verified:

- The ability to initiate and terminate transmission of video and data content via over-the- air datacasting from the HEC was verified.
- The ability to initiate and terminate transmission of video and data content via over-the-air datacasting from an HFD tablet computer in the field was verified.
- The ability to initiate and terminate transmission of video and data content via over-the-air datacasting from the SpectraRep administrator's laptop was verified.
- The ability to receive video and content sent by datacast over-the-air to laptops and tablets equipped with IncidentOne software and the required antenna was verified.
- The ability to transmit video from a cell phone operating on a commercial cellular network to the datacasting cloud services for injection into the datacasting dashboard or over-the-air transmission by datacasting was verified.
- The ability to transmit video from a handheld device operating on the Harris County Band 14 LTE network to the datacasting cloud services for injection into the datacasting dashboard or over-the-air via datacasting was verified.

- The ability to transmit multiple video streams simultaneously via datacasting was verified. On many occasions, four videos were received (and at one point, five videos were received) simultaneously at the HFD tablet. There was an issue (see below) that the number of videos that could be displayed did not always match the number of videos being received.
- The ability to receive and transmit video streams from multiple devices operating on either commercial cellular or Band 14 LTE networks was verified. At one point, sixteen different users were streaming video, which was distributed via LTE to the SpectraRep IncidentOne system. The test team member attached to HFD verified the simultaneous receipt of video streams from eleven users; however, no attempt was made to verify more users from that location.
- Quality of video received via over-the-air datacasting was useful at all times. HFD observers expressed their opinion that the video quality of data both from the dashboard (via LTE) and using datacasting over-the-air was excellent. There was an approximately 11 second latency for video streamed from a cell phone to a laptop via over-the-air datacasting, but this was not a concern to the HFD observers. The latency was approximately three seconds when streamed via LTE. The additional latency for the over-the-air transmission was a result of data buffering; these latencies could be reduced in future if desired.

Lessons Learned

There appeared to be some compatibility issues between the SpectraRep IncidentOne software and the HFD tablets. Initially, messages transmitted via datacasting were successfully received and attachments could be opened and read. However, subsequent messages could be read (and attached files opened) only if the IncidentOne application on the tablet was terminated and re-started. SpectraRep believes this is a compatibility issue associated with the use of 32-bit vs. 64-bit operating systems, and plans to resolve this issue prior to operational use at the Super Bowl.

During operations at the HEC, video streams being input to the IncidentOne dashboard were being terminated prematurely after a fixed time. Upon investigation, it was determined that this premature termination was a result of using an “Open Port” (Port 80 is continuously open, even on secure systems) because the HEC implemented a time limit on video streams entering the HEC via that specific port (in order to prevent the port from being used for viewing of inappropriate content). When video streams were input via a secure port with no time limit, the problem was resolved.

In addition, the test team reiterated its concern over the potential overloading of datacasting capacity. During non-emergency situations, datacasting will be limited to between 1 Mbps and 2 Mbps data rate (KUHT TV transmission currently supports up to 1 Mbps, although it is expected that this value will be raised to 1.5 Mbps for operations during the Super Bowl). As the number of users with the ability to transmit data through datacasting increases, the likelihood increases for the system to become overloaded resulting in data either not being transmitted or of degraded quality. For the Super Bowl, system usage will be managed by “CONOPS” (Concept of Operations). Transmit capability has been limited to two sites: the HEC (and the SpectraRep representative located at HEC) and HFD Chief Cook. The parties with transmit authority are aware of this issue and will coordinate via CONOPS to prevent collision or oversubscription on the system.

In the future, as access to datacasting broadcast transmissions is expanded and the system is operated under less controlled conditions, the potential for bandwidth saturation will increase. Eventually, the system will require an intelligent load-sharing capability with feedback to inform users that their messages cannot be sent over-the-air due to high transmit demand. It may even be useful to provide users with a continuous estimate of available capacity. So, even though users do not need access to other users’ content, they could be informed when others are using the system and to what extent.

An additional issue regarding test methodology and execution was observed; specifically, data collection during operational tests remains a challenge. Because of its minimal size, the test team is highly

dependent on public safety end users to provide feedback on the video quality. However, in an event like the Marathon or the Super Bowl, end users are busy ensuring the safety of the public. Therefore, there is a critical need for more effective quantitative and automated video quality measurement. In the interim, it would be helpful to deploy more test team members to collect data and observe operational use of the system.

Further Actions

As a result of testing of the expanded public safety architecture for use during the Super Bowl, the JHU/APL test team identified the following actions in order to make certain that the datacasting portions of the architecture perform successfully:

- The JHU/APL test team will configure additional equipment to enable it to receive and observe datacasting transmissions during Super Bowl security operations.
- A detailed test schedule and procedures will be developed. It is recognized that, due to the nature and priorities of Super Bowl operations, these procedures will need to be flexible to accommodate changes in operations by HPD and HFD.
- A detailed list of devices and user needs to be obtained.
- Issues identified above during the 12-15 January Marathon need to be resolved.
- An additional test of the datacasting system will be performed to assess load levels when the available television signal capacity is increased to 1.5 Mbps.
- There is a connectivity test scheduled for 25 January at the HEC.
- SpectraRep will develop a "quick reference guide" for end users.

Summary / Conclusions

At the request of the DHS S&T Directorate, representatives of JHU/APL and its sub-contractor, SpectraRep, participated in testing an enhanced integrated public safety telecommunications architecture, which is being deployed to support operations during the Super Bowl and other associated events hosted by the City of Houston during the first weekend in February. The test team assisted members of the HPD and HFD in configuring and deploying equipment to enable them to use the datacasting system integrated into their communications architecture, trained personnel on the use of the system, and tested the communications pathways to ensure full connectivity. In addition, the test team performed additional testing during the actual running of the Chevron Houston Marathon to assess system performance in representative operational conditions.

As the City of Houston and Harris County provided public safety coverage of the 2017 Houston Chevron Marathon and its associated events, video and data content were successfully sent to the Houston Public TV station for transmission by datacasting. These datacasts were successfully received by public safety personnel for the City of Houston and Harris County. Public safety users expressed the opinion that the video data quality received via datacasting was excellent. There appeared to be some compatibility issues associated with the use of 32-bit vs. 64-bit operating systems, and there are plans to resolve this issue prior to operational use at the Super Bowl. Also, it was found that using Port 80 as input to the SpectraRep software dashboard was a problem due to Houston security software causing it to time out prematurely; however, this issue was resolved by using a different port. In addition, there was some concern about datacasting congestion if KUHT TV transmission were limited to 1 Mbps, although it is expected that this will be raised to 1.5 Mbps for operations during the Super Bowl.

Although a number of small issues were identified and described above, the results of these tests created confidence that problems identified above would be rectified and the system would be ready for operational use during the Super Bowl.

APPENDIX E: Additional Discovery Green Maps

The following figures indicate the locations of cameras and access control points (ACPs) added to the Super Bowl Live Zone at Discovery Green Park in support of the Super Bowl Live events.

Figure E1: Super Bowl Live Zones: Temporary Video Camera Locations

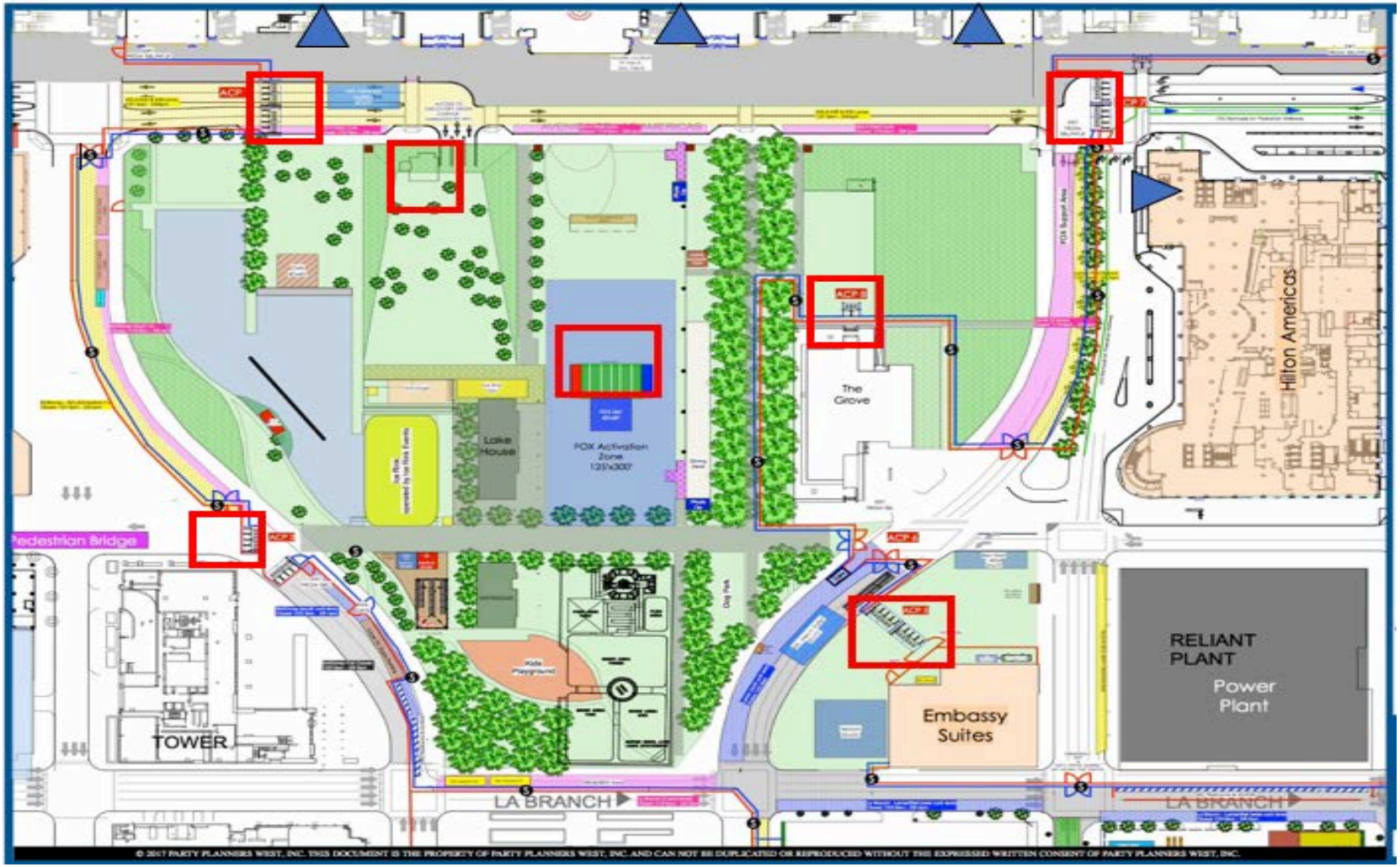

Figure E2: Super Bowl Live Discovery Green - ACP Map

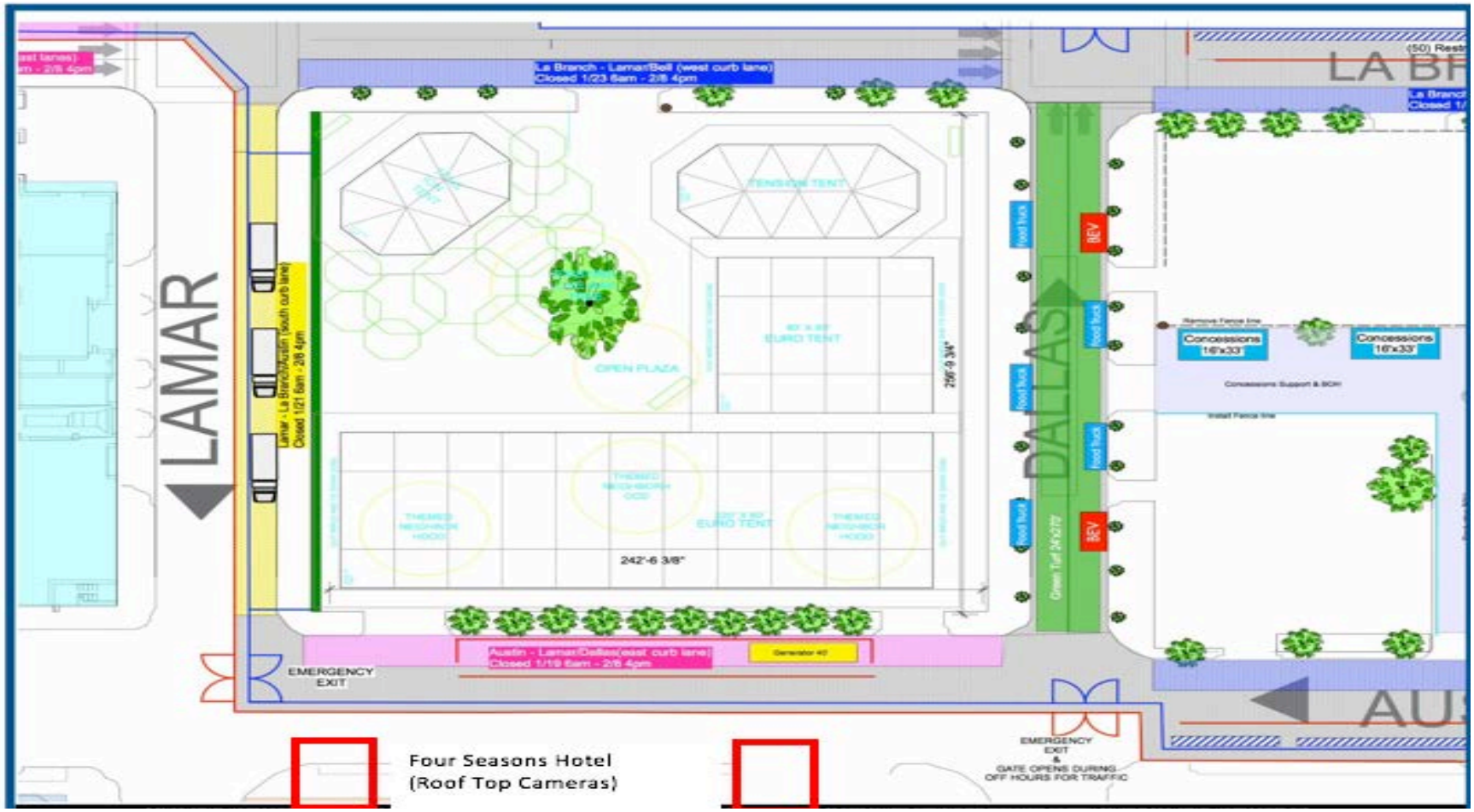

Figure E3: Super Bowl Live Discovery Green - Zone 1 Camera Locations

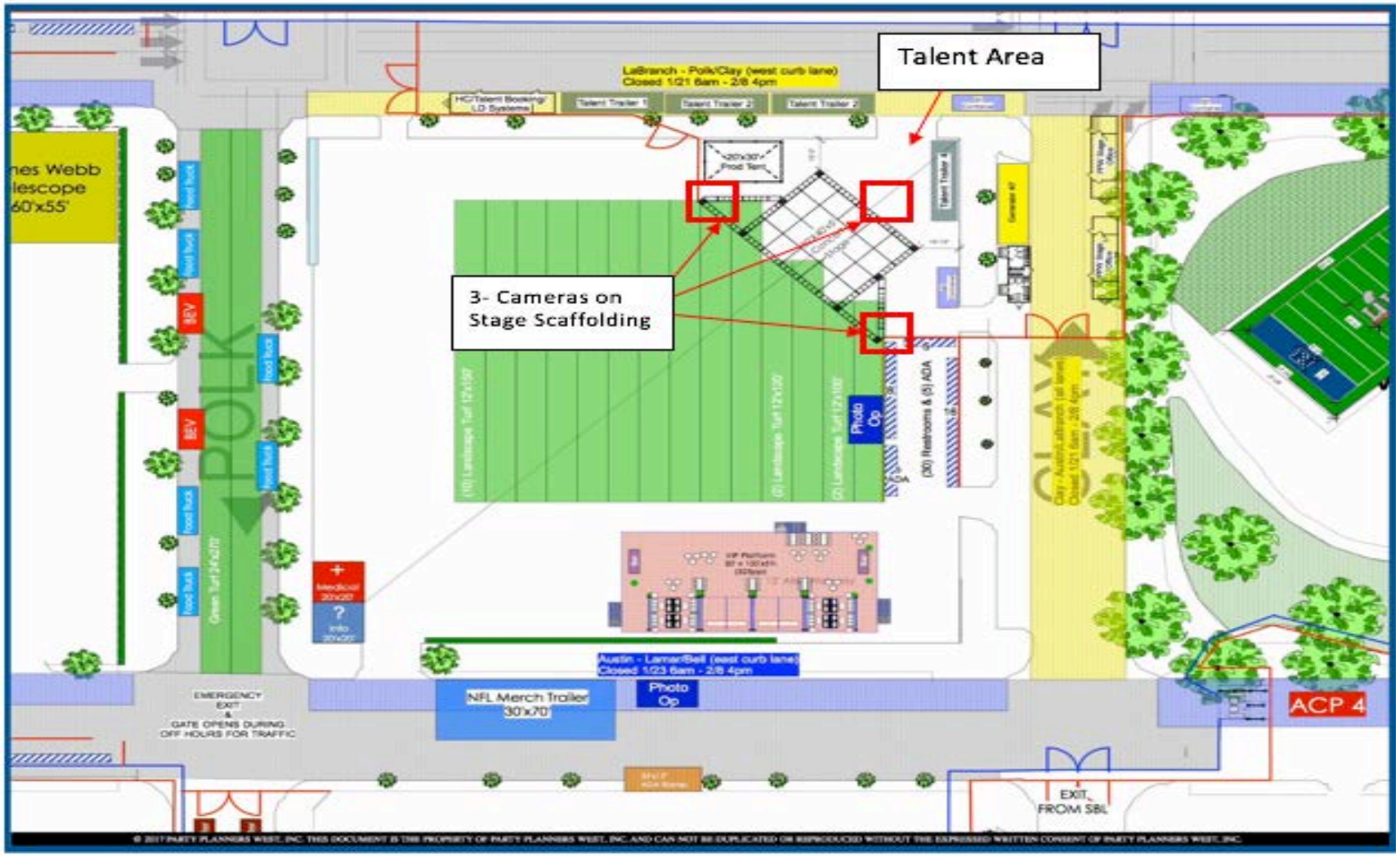

Figure E4: Super Bowl Live Discovery Green – Zone 3 Camera Locations

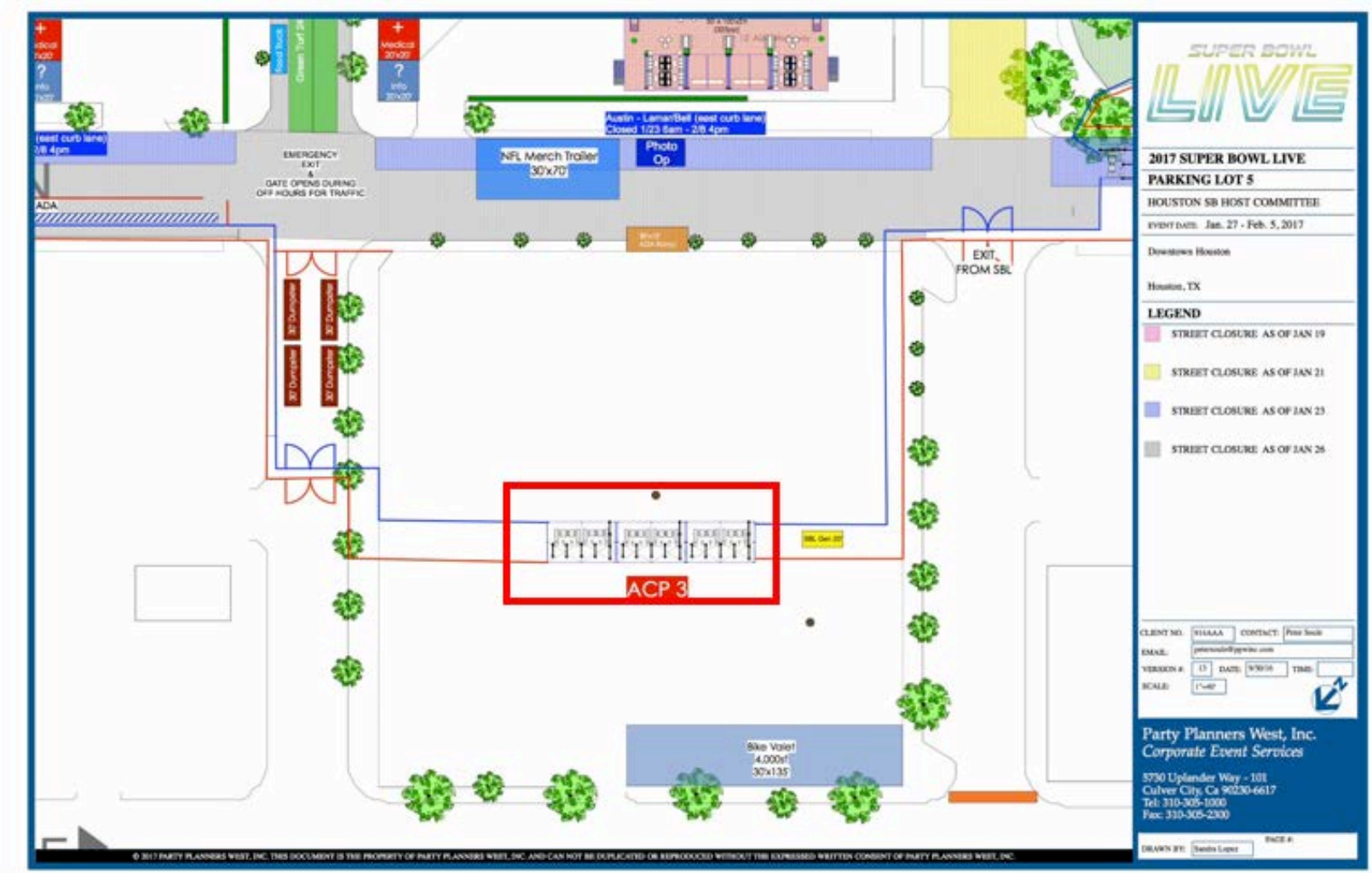

Figure E5: Super Bowl Live Discovery Green – Zone 5 ACP

APPENDIX F: Measurement Results from Comparison of Datacasting and Cellular Communications during Super Bowl LI

In order to assess the ability to download content at various points in a quantifiable manner, the test team used the Ookla speed test application (www.speedtest.net). This application performs a "ping" test to measure latency, as well as a download and upload speed test. All tests were performed with Wi-Fi disabled. The numbers documented in this report should NOT be considered rigorous measurements of the average speed of the network used (and it should be noted that speed test results can reflect factors other than just network performance). They are single point "snap shots" captured using a single smart phone. This test was intended to capture coarse data, not make precise measurements or characterize any individual network.

It should be noted that in order to not compromise information protected under Criminal Justice Information Services (CJIS) guidelines, there was no attempt to actually view video using the datacasting system. However, this did not limit the usefulness of the tests because it was felt that the test team's observations regarding video quality might not reflect the needs and experience of the actual end users.

Datacasting quality was assigned based upon a subjective combination of three measures provided by the datacasting IncidentOne software: signal strength, signal quality, and time since last packet received (latency). Reception was deemed as "good" if the signal and quality were consistently above "70" and gaps between packets were consistently less than one second. Reception was deemed "poor" if those levels were not consistently met, and "very poor" if those levels could not be met within a location. "Fair" was assigned in a couple cases in which there were "holes" in the reception quality (e.g., there were places with small areas – normally a couple square feet – where reception could not be achieved, but a good signal could be obtained by moving a few feet in either direction).

Results: Afternoon of 4 February

On 4 February, the test team recorded a number of measurements at various points around downtown Houston, moving from the area around the Town Hall, north toward Market Square and then east toward Minute Maid Park. From Minute Maid Park, the test team turned south toward Discovery Green and the area encompassed within Super Bowl Live. The team walked just beyond the perimeter set up around Discovery Green and then headed back toward downtown (see map in Figure F1).

Between approximately 13:45 and 13:55, a measurement was taken at the corner of Smith Street and Walker Street in the park across from the Hobby Center and diagonally opposite of the Town Hall (Table F1).

Table F1: Results from Smith and Walker Streets

	Quality		
	Latency	**Downlink**	**Uplink**
Cellular	35 -54 ms	10 Mbps	1.2 Mbps
Datacasting	Good; latency consistently less than 1 second		

Two measurements of cellular performance were recorded using the speed test; both tests were characterized by immediate connectivity and high data rates. Similarly, datacasting reception was achieved almost immediately. The test team observed datacasting performance for about 10 minutes in this location with minimal packet loss.

At approximately 13:30 measurements were recorded by the fountain on Texas Street between Louisiana and Capitol, across from the Jones Center for the Performing Arts.

Table F2: Results from Texas Street

	Quality		
	Latency	**Downlink**	**Uplink**
Cellular	37-56 ms	11.5 Mbps	1.3 Mbps
Datacasting	Fair; latency consistently less than 1 second		

The test team visited the site twice, once on the way from the parking lot to the Town Hall, and then on the way to Market Square. Initially, the test team tried to take measurements from a point near the fountain, and while it was able to obtain a solid signal, the team could not find the signal consistently. Upon circling back, around 14:10, a consistent signal was obtained from the center of the square facing the Bank of America Building.

From approximately 14:20 until 15:20, the test team took measurements in Market Square, in the historic downtown area of Houston. The following table summarizes the results:

Table F3: Results from Market Square

	Quality		
	Latency	**Downlink**	**Uplink**
Cellular	35 -65 ms	>10 Mbps	>1.3 Mbps
Datacasting	Very Poor		

The test team took a number of measurements within the square, consistently achieving high data rates, frequently in excess of 13 Mbps. In contrast, the test team found it difficult to acquire a signal anywhere in the square using datacasting. Despite attempting to acquire a signal from all four corners of the street, the test team could only acquire a signal from one point near the corner of Travis Street and Congress Avenue, and even that area of reception was very small. The signal could be lost even by taking two steps in either direction.

After completing its tests in Market Square, the team moved along Congress Avenue taking measurements at each intersection from Main Street over to Crawford Street at the north end of Minute Maid Park. The test team took measurements at each of the following intersections:

- Congress Avenue and Main Street
- Congress Avenue and Fannin Street
- Congress Avenue and San Jacinto Street
- Congress Avenue and Caroline Street
- Congress Avenue and Austin Street
- Congress Avenue and LaBranch Street
- Congress Avenue and Crawford Street

Performance of the two systems is characterized as follows:

Table F4: Results from Congress Avenue

	Quality		
	Latency	**Downlink**	**Uplink**
Cellular	35 -65 ms	>10 Mbps	>1.0 Mbps
Datacasting	Good; latency consistently less than 1 second		

Cellular download rates of at least 10 Mbps and uplink rates of at least 1 Mbps were achieved at each point along the route. Similarly, at each point along the route, datacasting reception was also good, at

least while stationary to take measurements. Last-packet-received times of less than one second were observed at each point.

The test team took four measurements at the corner of Crawford Street and Congress after the first attempt to run the speed test returned a download speed of 2.1 Mbps. However, each of the subsequent three measurements returned download speeds of better than 10 Mbps, including download speeds of as high as 13 Mbps. It should also be noted that the test team observed no undue latencies in trying to connect to the speed test.

Next, the test team walked south along the western side of Minute Maid Park toward Discovery Green. The team reached the southern end of the stadium, at the corner of Crawford Street and Texas Avenue, at approximately 16:15. As the team paused to take a measurement, the trailing edge of the protesters was observed marching eastward along Rusk Street (Note: this was completely serendipitous; there was no attempt to coordinate testing to the march. While aware that protests were planned, the test team made no attempt to determine when or where they were occurring or to modify testing to capture data associated with the march).

Table F5: Results near Minute Maid Park

	Quality		
	Latency	**Downlink**	**Uplink**
Cellular	166 ms	0.8 Mbps	0.2 Mbps
Datacasting	Good; latency consistently less than 1 second		

By the time the test team reached the corner of Crawford Street and Texas Avenue, it had become difficult to run the speed test. There was a latency of several seconds required to run the test, and when sufficient bandwidth was available, it was limited. By contrast, the datacasting signal remained strong and the time between packets was never greater than a second (the datacasting software tool's lowest level of granularity).

From this point, the test team attempted to take measurements from just outside the fenced perimeter of the Super Bowl Live events. There was a three to four block line to enter Discovery Green via Entry 1 on Avenida de las Americas. The test team attempted to collect data from between 16:30 and 17:00 at the following intersections:

- Capitol Street and Crawford Street
- Rusk Street and Crawford Street
- Rusk Street and LaBranch Street
- Rusk Street and Austin Street
- Walker Street and Austin Street
- McKinney Street and Austin Street
- Dallas Street and Austin Street
- Dallas Street and Caroline Street
- Caroline Street and Polk Street

Over a period of forty minutes, the latency test failed consistently. During that time, the test team was only able to achieve two "successful" speed tests:

Table F6: Results near Crawford Street

Location	Latency	Downlink	Uplink
Capitol/Crawford	215 ms	0.65 Mbps	0.25 Mbps
Rusk/Crawford	188 ms	0.7 Mbps	0.28 Mbps

Even these results may over-state actual performance. Although the test team didn't have an accurate method in place for measuring how long it took to begin each speed test, it was typically more than a minute for each attempt, and the majority of the attempts to run the speed test resulted in a latency test failure.

The datacasting signal was consistently strong throughout this time. There were a couple of locations along Austin Street, between Rush Street and McKinney Street, where a strong datacasting signal could not be achieved, but in each case, moving even a couple steps was sufficient to restore the signal.

At 17:00, another group of protesters were sighted marching south along Caroline Street at the intersection of Caroline and Polk. There were a few minutes of strong cellular signal after the protesters passed; however, the signal was quickly lost again.

Table F7: Results from near Caroline and Polk Streets

Location	Latency	Downlink	Uplink
Polk/Caroline	51 ms	5.0 Mbps	1.0 Mbps
Polk between Caroline and San Jacinto	70 ms	3.8 Mbps	0.1 Mbps
Polk/San Jacinto	39 ms	6.6 Mbps	0.15 Mbps
Dallas/San Jacinto	67 ms	0.76 Mbps	0.1 Mbps
Lamar/San Jacinto	56ms	0.75 Mbps	1.24 Mbps

The test team walked from there west along Walker Street and then north along Main Street, taking periodic random measurements of the cellular speed as it went. As the test team moved west, the signal began to get stronger. The test team observed data download speeds of between 5 and 7 Mbps in the area along Main Street between Main Street Square Station and Central Station Main (between Rusk Street and Capitol Street). North of Central Station, download speeds of between 9.0 Mbps and 13.0 Mbps were observed. The test team stopped taking measurements for the afternoon at approximately 17:45.

Figure F1 contains a map of the cellular download rate. The white circle at the corner of Austin and Polk indicates a location at which the test team was unable to perform the speed test and then achieved a high download rate a few minutes later.

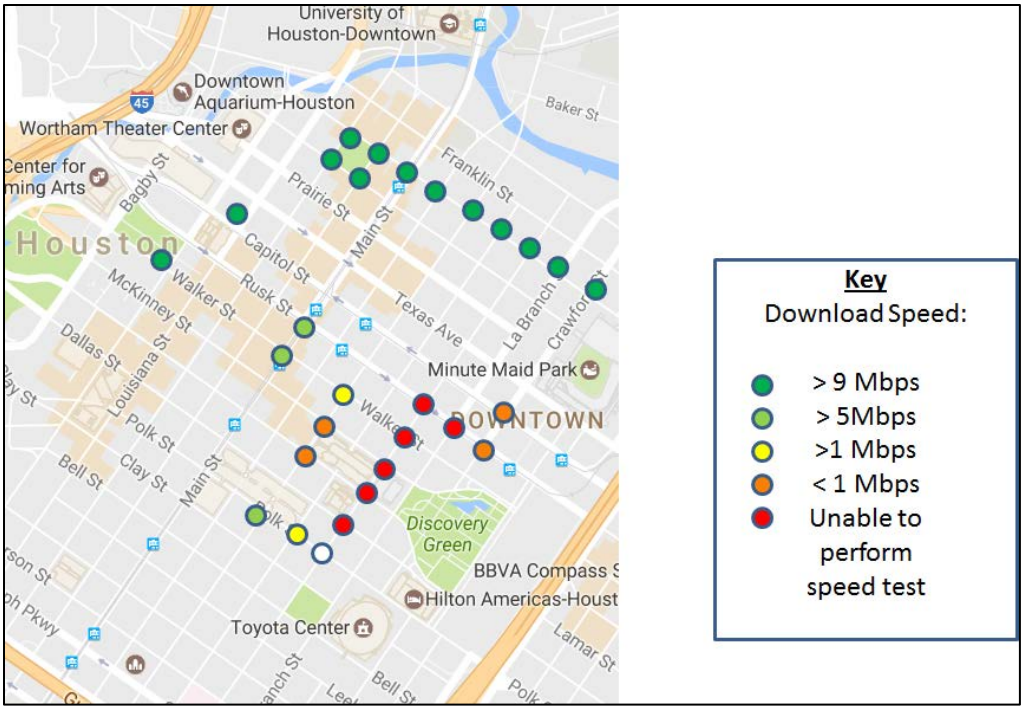

Figure F1: Map of Cellular Download Rates Measured on the Afternoon of 4 February

Figure F2 contains a map showing datacasting reception measured on 4 February. The map reflects the generally strong signal achieved everywhere except for the area around Market Square. Areas of yellow reflect locations in which intermittent loss of coverage was observed. For example, the block along Austin Street, between Rush and McKinney Street has been designated "yellow" to indicate that there were places, most no more than a few feet in extent, where reception could not be achieved.

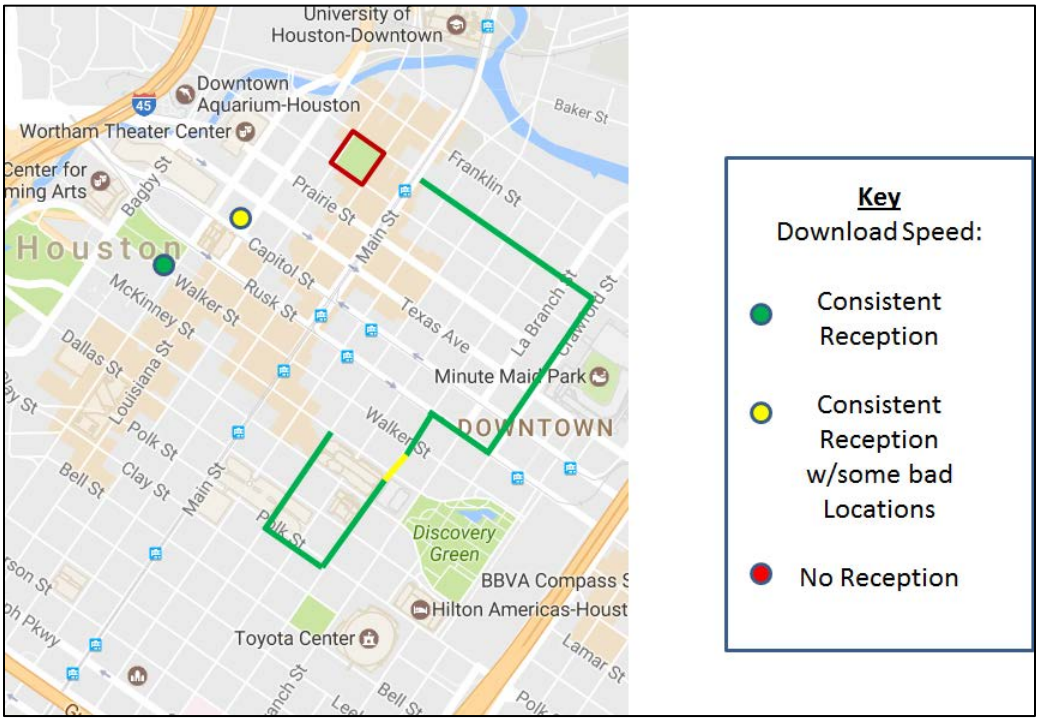

Figure F2: Map of Datacasting Reception Observed on the Afternoon of 4 February

Results: Evening of 4 February

Testing recommenced at approximately 18:45. The test team walked from Market Square toward Central Station Main. Along the way, the team took informal random measurements. Consistent with earlier measurements, download speeds of 9 to 13 Mbps were recorded toward Market Square, while download speeds near Central Station were closer to 5-6 Mbps.

The test team turned east along Lamar Street in order to capture data in a crowded area where congestion was expected. Between 19:10 and 19:20, the test team captured the following results at the following locations:

Table F8: Results from walking east along Lamar Street

Location	Latency	Downlink	Uplink
Lamar/San Jacinto	43 ms	2.4 Mbps	0.64 Mbps
Lamar/Caroline	48 ms	1.1 Mbps	0.28 Mbps
Lamar/Austin	130 ms	0.4 Mbps	0 Mbps

No additional successful speed tests could be performed. Measurements were attempted at the following intersections:

- Dallas Street and Austin Street
- Polk Street and Austin Street
- Polk Street and Caroline Street

Measurements were also taken in the Parking lot abutted by Austin, Polk, Caroline, and Clay streets. Finally, the test team returned westward along Lamar, measuring the increase in available capacity as one moved away from the Super Bowl Live activities.

Table F9: Results from walking west along Lamar Street

Location	Latency	Downlink	Uplink
Lamar/San Jacinto	77 ms	2.7 Mbps	1.5 Mbps
Lamar/Fannin	56ms	3.0 Mbps	1.4 Mbps
Lamar/Main	54 ms	3.1 Mbps	1.4 Mbps
Lamar/Travis	61 ms	8.9 Mbps	1.4 Mbps
Lamar/Milam	60 ms	11.3 Mbps	1.2 Mbps
Town Hall	63 ms	5.66 Mbps	1.1 Mbps
Smith/Rusk	59 ms	5.3 Mbps	1.2 Mbps

Figure F3 contains a map identifying locations at which measurements were made and the approximate download rates achieved.

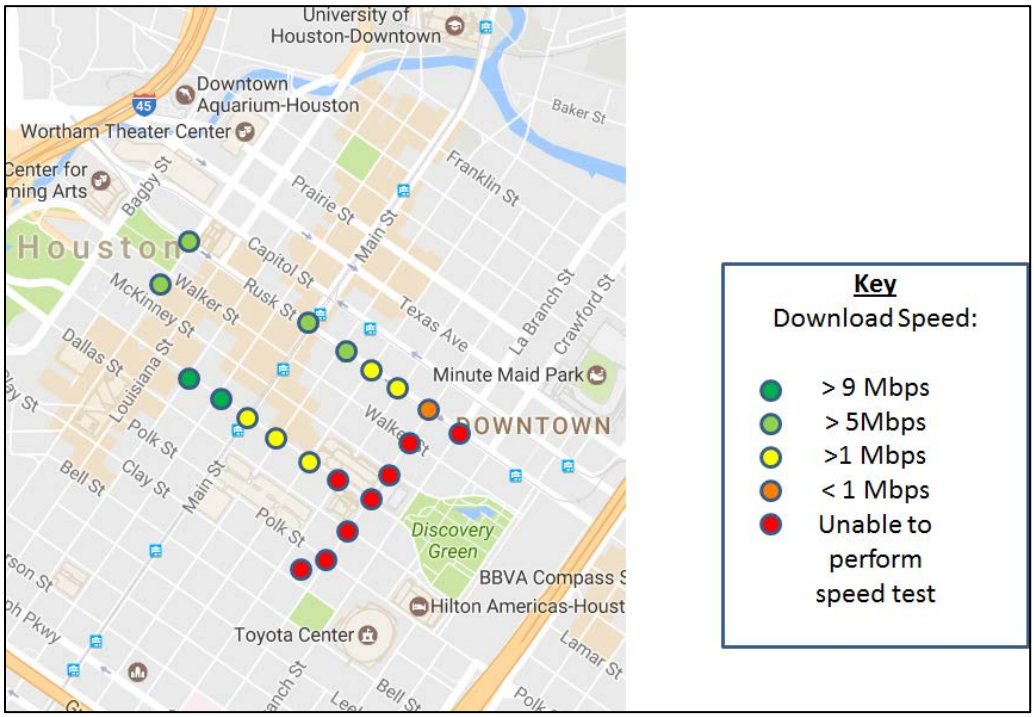

Figure F3: Cellular Download Rates Measured on the Evening of 4 February

Results: Afternoon of 5 February

Super Bowl LI took place on 5 February. On Sunday afternoon, the test team re-traced its approximate route from the day before, taking measurements at various points from Town Hall to Market Square to the downtown area around Central Station Main to Discovery Green. The team began taking measurements at approximately 12:45 and arrived at Discovery Green, at the entrance to Super Bowl Live at approximately 13:30. Measurements taken along the route are documented in Table F10.

Table F10: Results between Town Hall and Discovery Green

Location	Latency	Downlink	Uplink
Louisiana/Capitol	66 ms	11.1 Mbps	1.2 Mbps
Louisiana/Texas	64 ms	11.9 Mbps	1.4 Mbps
Smith/Prairie	63 ms	10.2 Mbps	1.4 Mbps
Preston/Milam	60 ms	7.7 Mbps	1.3 Mbps
Congress/Milam	35 ms	6.7 Mbps	1.4 Mbps
Preston/Travis	34 ms	7.7 Mbps	1.4 Mbps
Congress/Travis	34 ms	8.6 Mbps	1.2 Mbps
Main/Preston	66 ms	9.2 Mbps	1.4 Mbps
Main/Capitol	65 ms	5.8 Mbps	1.4 Mbps
Main/Rusk	53 ms	5.5 Mbps	1.4 Mbps
Rusk/Fannin	36 ms	8.2 Mbps	1.4 Mbps
Rusk/San Jacinto	35 ms	7.0 Mbps	1.4 Mbps
Rusk/Caroline	68 ms	0.8 Mbps	1.4 Mbps
Rusk/Austin	57 ms	0.8 Mbps	1.4 Mbps

The test team attempted unsuccessfully to execute the speed test at the following locations outside the Super Bowl Live security perimeter:

- Rusk Street and LaBranch Street
- Rusk Street and Crawford Street
- Crawford Street and Walker Street
- At Entry 2 at the intersection of Crawford Street and McKinney Street

Figure F4 contain a map for measurements taken outside of Discovery Green.

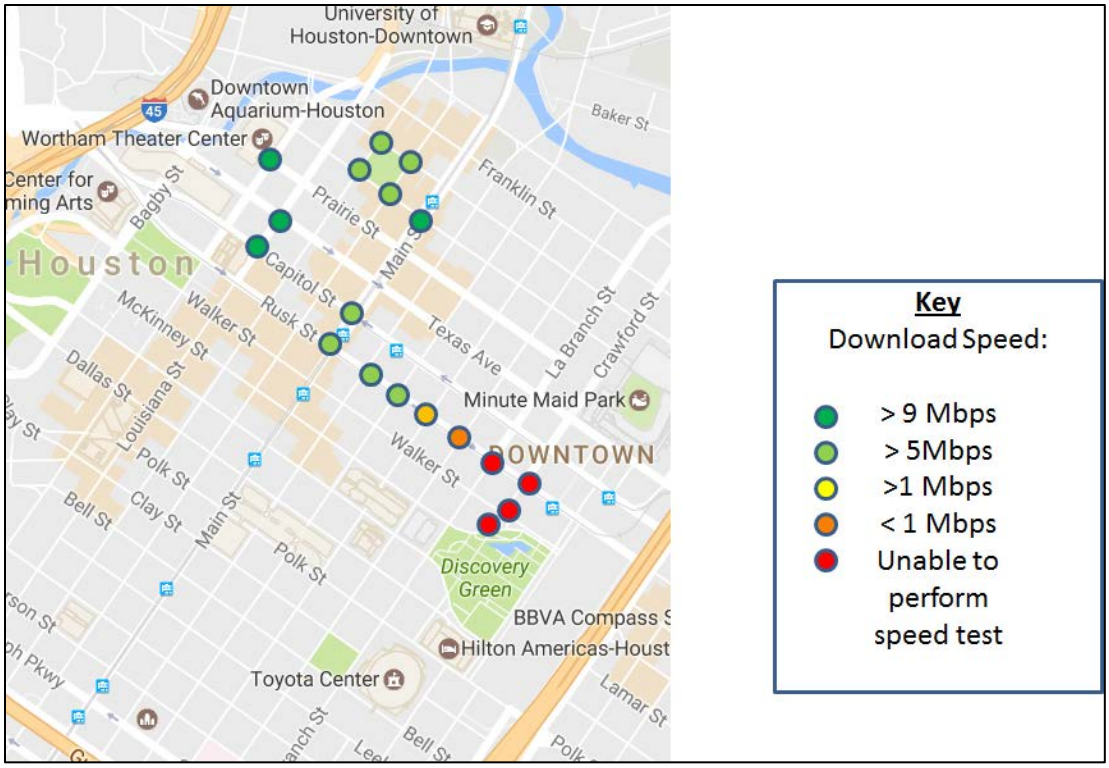

Figure F4: Measurements Recorded on the Afternoon of 5 February outside Discovery Green

The test team began taking measurements inside of Super Bowl Live from 14:00 until closing at 15:00. Measurements varied widely within Discovery Green. Measurements taken a few minutes apart from the same location yielded substantially different results. See Figure F5.

In general, the test team observed consistently high download rates in the area around Root Square, where the larger live music stage was located. Download rates measured on Discovery Green and in the area where "Houston Live" was located (in the block surrounded by Dallas Street, Austin Street, Lamar Street and LaBranch Street). In these areas, there were a few failed speed tests, but the majority was successful in achieving a measurement. Most of the speed tests yielded download speeds between 2 and 5 Mbps, although values between 1 and 2 Mbps and as high as 7 Mbps were also observed. The download rate was highest near the George R. Brown (GRB) Convention Center. Finally, speed tests generally yielded values of less than 1 Mbps and were unsuccessful more often than not in the area of the food trucks between Houston Live and the Live Music stage. Figure F5 contains an approximate map of the measurements.

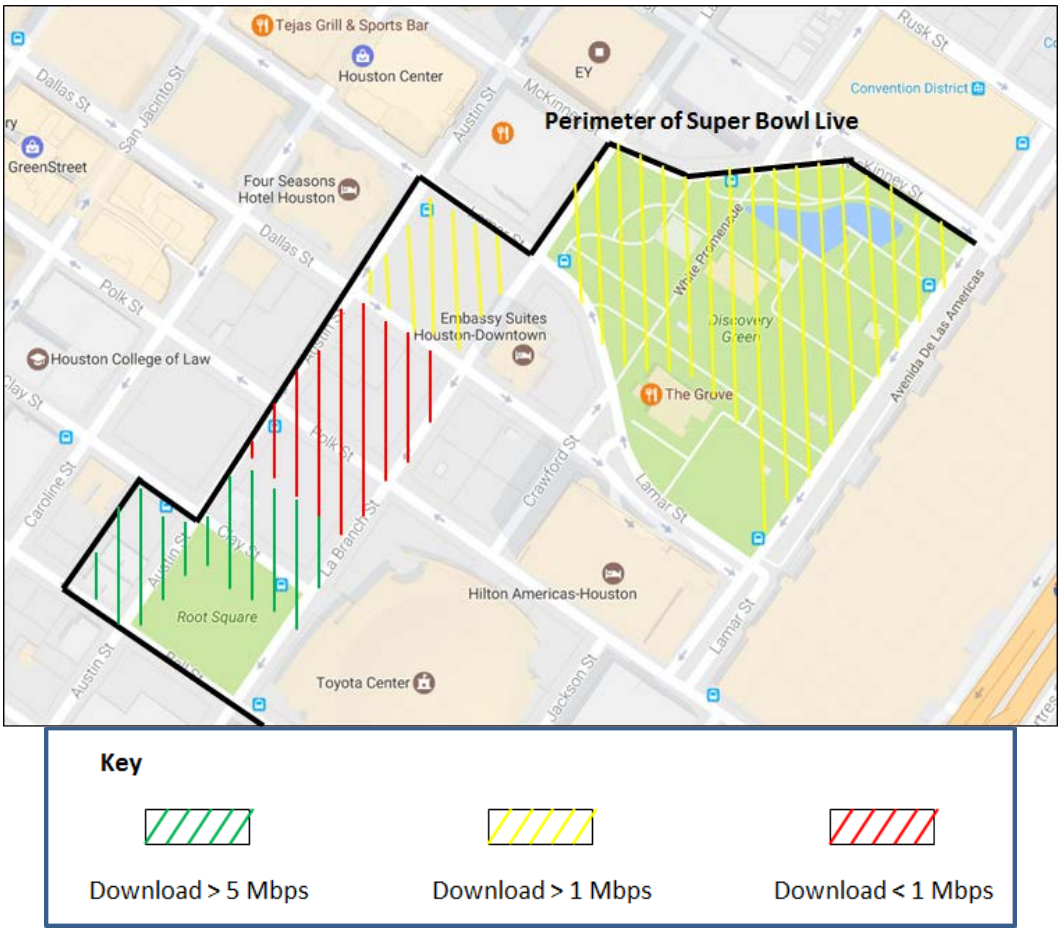

Figure F5: Map of Download Rates Measured at Super Bowl Live Event

Results: Evening of 5 February

The test team made its final set of measurements around NRG stadium. Measurements began at 17:30, and the test team continued for approximately an hour. Due to security arrangements for the Super Bowl, access to NRG Stadium was limited. As a result, the test team walked a path beginning at the NRG Metro station, moving north up Fannin Street, west along LaConcha Lane, and then south along Kirby Drive to the entrance at Gate 11 (see map in Figure F6).

The test team found one location in which it was able to download data with relative ease. In two separate measurements performed ten minutes apart, the test team observed download speeds of better than 11 Mbps at a point on Fannin Street near the NRG Center.

Table F11: Results from Fannin Street

Time	Latency	Downlink	Uplink
17:35	67 ms	12.7 Mbps	1.5 Mbps
17:44	60 ms	11.1 Mbps	1.4 Mbps

Other than that, the test team was mostly unable to collect measurements. It consistently took longer than a minute to perform each test, and on most attempts, the latency test failed, yielding no measurements. On the few occasions on which a test did achieve a successful measurement, the test team observed long latencies and low download and upload rates:

Table F12: Results from the Stadium Metro to Gate 11

Time	Approximate Location	Latency	Downlink	Uplink
17:30	Stadium Metro	169 ms	0.4 Mbps	0.3 Mbps
17:40	Stadium Metro	259 ms	0.7 Mbps	0.4 Mbps
17:50	7900 Fannin	178 ms	0.8 Mbps	0.5 Mbps
17:55	Fannin and La Concha	174 ms	1.0 Mbps	0
18:00	LaConcha Lane	141 ms	0.8 Mbps	0.3 Mbps
18:10	Kirby Drive Gate 11	148 ms	0.8 Mbps	0.3 Mbps
18:20	LaConcha Lane	341 ms	0.3 Mbps	0.3 Mbps

The test team ended its testing at the Smith Lands Metro station, where it was able to collect a robust, although slightly sporadic data capability. Figure F6 provides a map of the route taken by the test team and the location of successful speed tests. It should be noted that along the route were numerous "tailgating parties" where people were parked and watching the game on television. While the test team did not inquire, it is possible that these people had antennas and were watching via broadcast television (an indication that there would have been a strong datacasting signal).

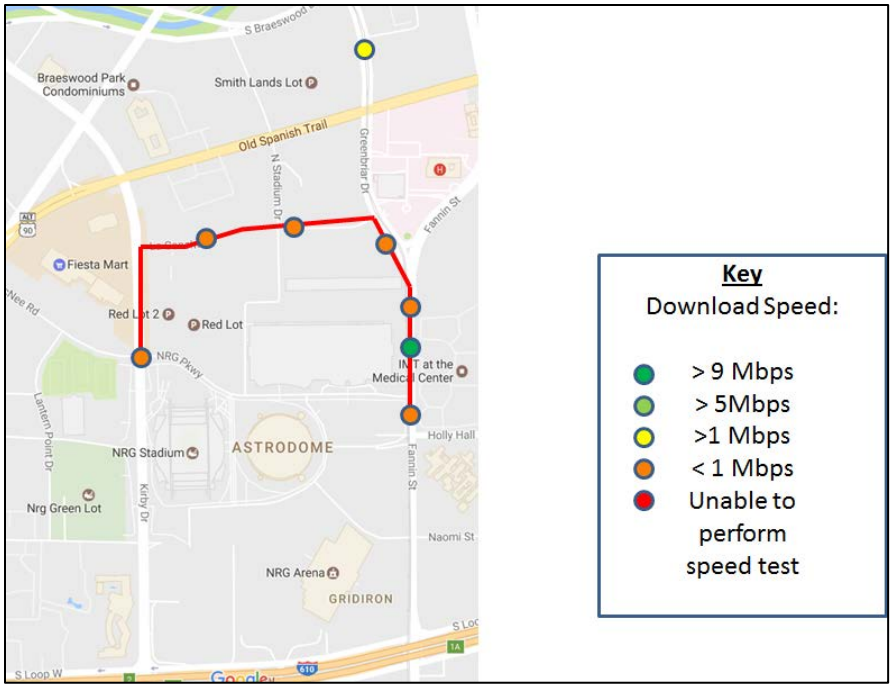

Figure F6: Download Measurements Taken around NRG Stadium

Conclusions

Based upon these measurements, the test team was able to draw the following conclusions:

- Outside of the area around Market Square in the historical section of downtown Houston, datacasting reception was excellent at every location. There were two additional locations in which there appeared to be small dead zones – small areas in which no signal could be obtained – but otherwise datacasting reception was high throughout the testing. As long as the datacasting signal was able to lock, the data rate never changed.
- As expected, download speeds were substantially reduced in areas of high congestion. On Saturday 4 February, it became almost impossible to even run the speed test in areas adjacent to the Super Bowl Live event.
- The test team observed better reception inside the NFL Live event on Discovery Green than in the blocks adjacent to the event. This could be due to the fact that the test team was not able to enter the Super Bowl Live event when the crowds were largest (there was a couple hours wait to enter Discovery Green on Saturday). However, it is also possible that at large events such as Super Bowl Live, communications networks are augmented sufficiently to deal with the expected additional traffic within the event area, but not in the immediately adjacent areas. This study does not provide sufficient evidence to draw any definite conclusion, but it would nonetheless suggest an additional follow-up analysis.

However there are some caveats to this analysis:

- The tests were performed with a single cell phone with a single service provider; there were not sufficient resources for a more rigorous test.
- Tests did not address effects of having a dedicated Band 14 capability. At this time, it is not known whether the presence of a network with 10 MHz of downlink bandwidth would reduce the need for a redundant path. It is also not known whether increased demand for video in the future will place sufficient additional stress on the network where datacasting has increased day-to-day value by being used as a way of delivering video and content with large numbers of targeted recipients.