ATSC 3.0 File Delivery to Multiple Markets

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Summary Report - 6/01/2022

Abstract— **As part of continuing efforts to investigate and develop Automotive Industry use cases for ATSC 3.0 delivery of live and linear entertainment, as well as common file-type payloads, a collaborative series of industry tests have been performed, of which the test described herein is the third and latest. Testing, to date, has demonstrated the ability of ATSC 3.0's robust physical layer techniques to enable reliable reception of multiplexed Video and Audio streams while simultaneously supporting reception of datacast payloads transmitted over a separately constructed Physical Layer Pipe (PLP), customized for robust mobile distribution and reception. Building on Sony's previous tests, measurements, and observations [4], this paper investigates the further potential and benefits postulated in the report of previous testing with respect to potential utilization of an alternative to the Application Layer Forward Error Correction (AL-FEC) method specified in ATSC 3.0 standard A/331 (i.e., RaptorQ). It has been demonstrated that the alternative AL-FEC used in the currently-reported tests (KenCast Fazzt) can:**

- Be Optimized for robust, mass distribution of live, linear, and file-based payload types via ROUTE/DASH Non-Real Time (NRT) multicasting
  - The alternative AL-FEC demonstrated the ability to withstand significant network impairments as shown by:
    - Delivery of a 7.6-GB file
    - Continuous reception of a 720P stream over ROUTE/DASH NRT
    - Continuous, "errorless" delivery/reception while switching from one ATSC 3.0 emission to another
  - The alternative AL-FEC provides the potential for FEC "Encryption"
    - With or without LLS, SLT, TSI, and TOI compliance
    - Using hidden payloads (which do not disrupt broadcast operations and which provide additional security) for critical infrastructure IoT
      - Excerpt from Sony paper [4]
        - "To not disturb media Services from a broadcaster, a separate automotive APP-based Service (`SLT.Service`@serviceCategory = 3) with (`SLT.Service`@hidden = true) enables broadcasters to support a separate automotive application that supports file delivery to devices that know to look for that application. Large file sizes can be supported in a range of payload rates depending on how much spectrum is shared with the broadcaster media. "
  - The alternative AL-FEC provides the potential to enable robust ROUTE/DASH NRT datacasting via KenCast Fazzt AL-FEC within a PLP constructed to optimize A/V mux bandwidth and/or channel capacity
  - The alternative AL-FEC provides the potential for an adaptive choice of FEC framework to ATSC 3.0 to perform measurement based comparisons with RaptorQ over a variety of datacasting configurations to consider;
    - Location- & Terrain-specific field recording and analysis of ATSC 3.0 reception data by available channel
    - Automated collection and AI/ML analysis of ATSC 3.0 field emission data as a basis for
      - ATSC 3.0 national datacasting network densification analysis & planning
      - ATSC 3.0 MOD-COD & AL-FEC (option) optimization
- Provide FEC-enabled ATSC 3.0 channel discovery & bonding (3GPP like split, switching and steering) functionality
  - AL-FEC payload discovery and processing via proprietary header

- o Split functionality, i.e., splitting of origin file and/or stream payloads for continuous FEC transmission
- o Switching & Steering of multiple, continuous FEC payloads via underlying IP routing and switching
- o Errorless, continuous reconstruction of the origin payloads from multiple continuous FEC payloads (bonding and/or 3GPP split, switch, steer functions) for robust, RF optimized file delivery and/or SRT streaming
- o Alternative AL-FEC demonstration of scalable bandwidth via simultaneous discovery & processing of scanned ATSC 3.0 emission channels
  - ▪ Points to potential use of SONY "Clover" as a means of simultaneous emission discovery and processing via all four receivers by the KenCast AL-FEC application
    - To enable MFN bandwidth scalability
    - To enable Continuous FEC Encryption
    - To enable Heterogeneous configurations
    - To enable redundancy and packet recovery
- o Alternative AL-FEC demonstration of bonding (and/or 3GPP split, switch, steer functions) over multiple ATSC 3.0 emission channels to provide more usable bandwidth

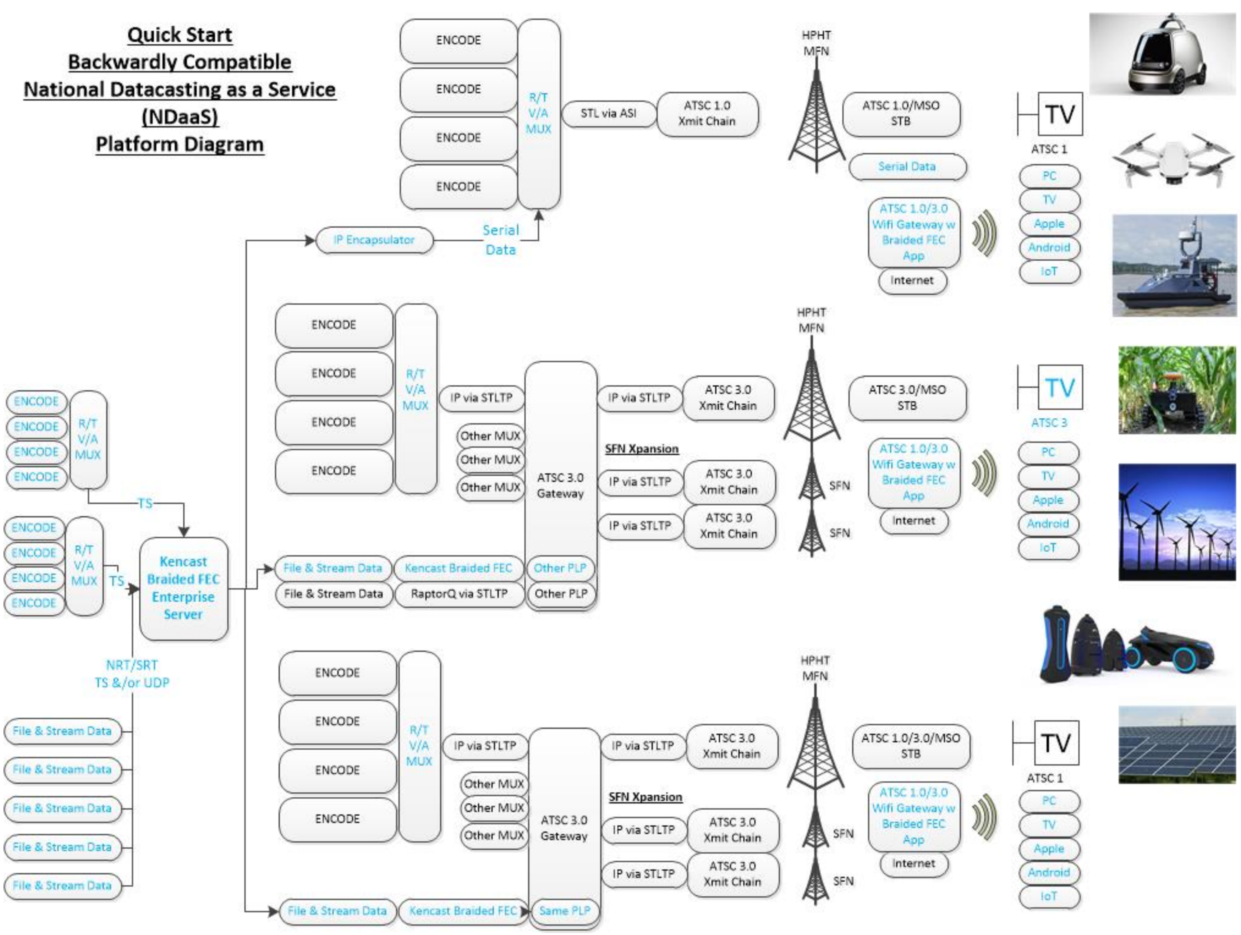

Table 0.1 National Datacasting as a Service (NDaaS)

I. INTRODUCTION

One of the most sought-after markets targeted by proponents of NEXTGEN TV is the set of automotive use cases.

This paper demonstrates how an application-oriented design approach can offer the flexibility to automate provisioning of services given:

- A variety of Vendor Gateways
- A variety of Operator Configurations
- A variety of Facility Ownership
- Traditional Friction Regarding Channel Carriage created by
    - Regulatory interpretation of retransmission policies and boundaries
    - Contractual access to channel capacity by the system operator and/or owner
    - Existing Day of Air operational constraints
        - Typically Day of Air operations seeks to minimize system modifications
- Speed to Market requirements

II. ATSC 3.0 A/331 STANDARD

A basic description of the ATSC 3.0 A/331 standard, "Signaling, Delivery, Synchronization, and Error Protection" is available in the prior phase report [4].

III. FILE DELIVERY

Current presumptions are that delivering a file to multiple markets needs to involve broadcasters working together in order to route signaling to receivers and to notify them of the availability of each other's Services for reception of the jointly-carried content. This Phase 2.0 demonstration of an AL-FEC platform provides an alternative to the presumption of necessary station level collaboration and coordination by enabling independently booked and scheduled file and stream transport events to be executed and connected through pre-contracted access to an owner/operator mix of facilities with specific bandwidth and connectivity characteristics associated with specific emission facilities, vendor gateways and/or day of air configurations.

The current understanding of the ATSC 3.0 framework for delivery of Route DASH NRT payloads across MFN network structures has been constrained by limitation to the capabilities of the specific RaptorQ implementation in the ATSC 3.0 standard; i.e., no means of "bonding" of NRT payloads (with 3GPP ATSSS like split, switch, steer capabilities) has been described.

In contrast, Kencast's Continuous FEC by virtue of it's 3GPP ATSSS like split, switch, steer capabilities can enable numerous additional benefits not available in the current body of the ATSC 3.0 standard such as enabling NRT/SRT routed payloads over Route DASH as a proprietary platform, software managed capability unconstrained by the component level interoperability demands of designing a national service composed of a vast universe of hopefully interoperable consumer devices.

The following are the MOD-COD parameters which were utilized in last two Phases of the Michigan Coast to Coast test to provide a consistent baseline configuration to measure performance improvements in a variety of categories without being subject to baseline system changes. [4]

Parameter	PLP0 (Mobile)	PLP1 (Stationary)
RF Center Frequency	575 (WMYD), 599 (WKAR & WOLP), 479 (WXSP) [MHz]	
LDM	Core	Enhanced: 6dB Injection Level
FFT Size	16K	
Pilot Pattern	8_2	
Pilot boost	1	
Guard Interval	GI4_768 (111us)	
Preamble Mode	(Basic: 3, Detail: 3) Pattern Dx = 8	
Frame Length	203 msec	
Number of Symbols	80	
PLP size	1030513 cells	
Frequency Interleaver	On	On
Time Interleaver	CTI (1024 rows) → max time spread on both Core & Enhanced PLP	
Modulation	QPSK	256 QAM
Code Rate	4/15	8/15
Code Length	64800 bits on both Core & Enhanced PLP	
Contents	Common Service ID = 5007 + FILES	Various Service ID's across 4 different RF channels
Bit Rate [Mbps]	2.67	21.53
Required C/N [dB] (AWGN)	-2.90	20.88

Table III.1 Transmission Parameters

IV. PLP0 Issues

Previously committed bit bandwidth for commercial services on PLP0 at WOLP and WXSP, which could not be impacted, resulted in reduced PLP0 bandwidth availability for testing. This provided more of a "real-world" test than otherwise would have been the case.

V. Driving Routes and Signal Coverage

The drive route for Phase 2.0 was the same route taken in the Phase 1.5 test [4]. The origination points for each of the two days of drive testing started at the MGM Grand Casino in Detroit, Michigan, following route I-96 to Grand Rapids, Michigan. The return trip terminus each day was the garage facilities located at station WXYZ in Southfield, Michigan.

Figures V.1 and V.2 below show predictively modeled signal level footprints, using Longley-Rice and TIREM propagation models, respectively, to predict signal levels received from the combination of transmission towers during each drive test.

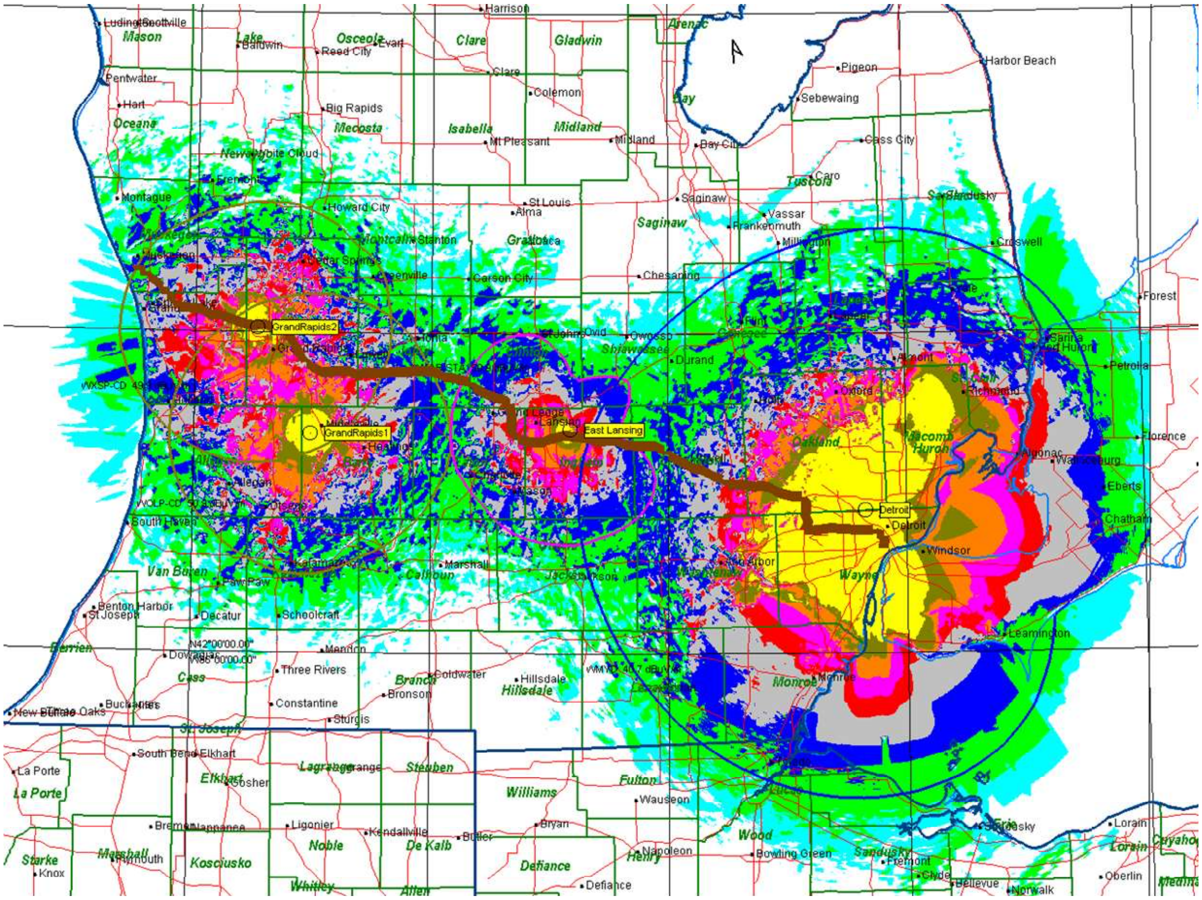

Figure V.1 Longley-Rice Field Strength Prediction

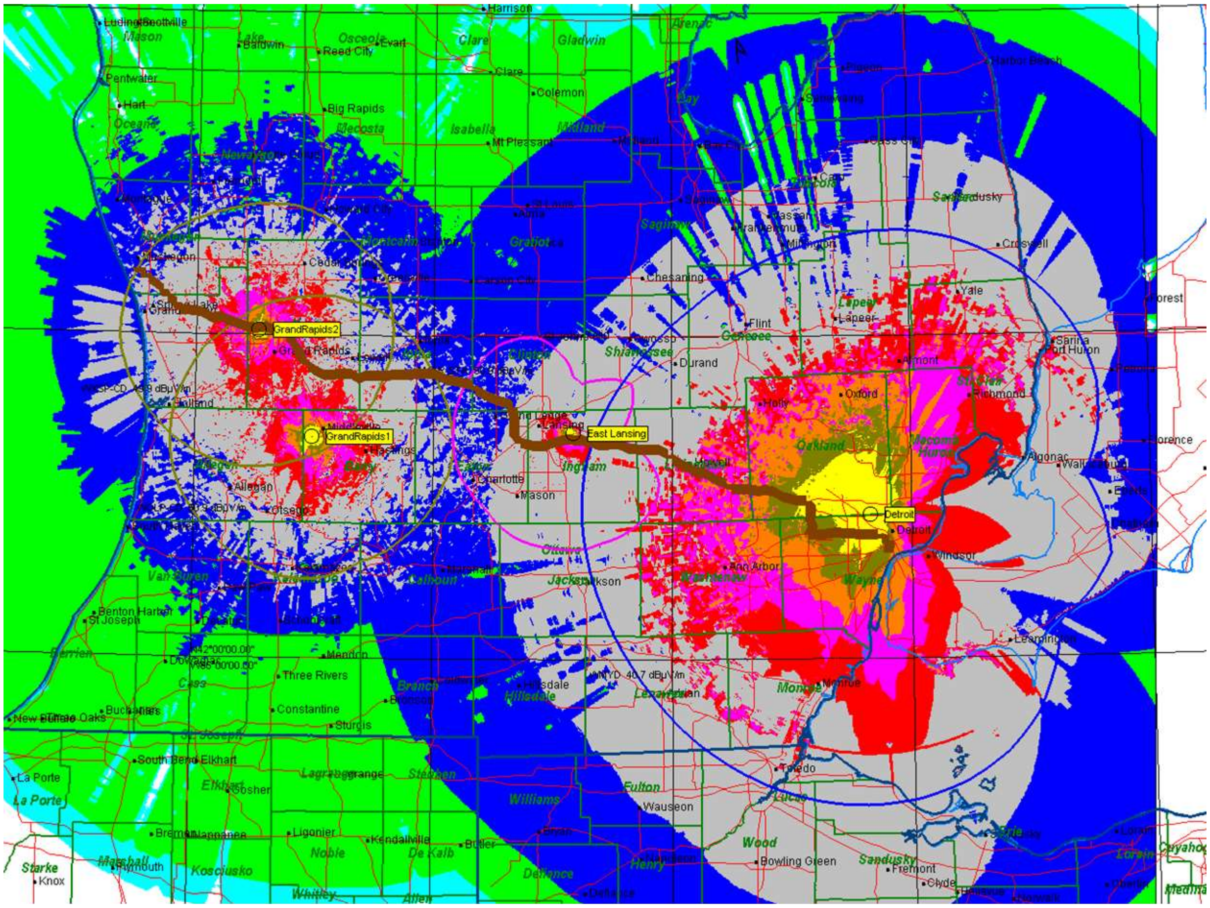

Figure V.2 TIREM Field Strength Prediction

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Both the Longley-Rice and TIREM Field Strength Predictions indicate significant overlap of ATSC 3.0 emissions between WMYD Detroit and WKAR East Lansing. Because of operation of the two stations on different channels (31 and 35, respectively), the signals would be non-interfering, with content associated with both A/V streams and NRT file transport carried in PLP0 of both stations enabling performance measurements with respect to reception hand-offs between markets.

In contrast, predicted hand-off performance between WKAR East Lansing and WOLP Grand Rapids was expected to be less than optimal due to anticipated co-channel interference between the two stations, both of which operate on Channel 35. Such interference was previously noted in observations of Phase 1 testing using a NASA Select A/V Stream and in Phase 1.5 using A/331 ROUTE/DASH NRT file transfers. Moreover, a significant predicted reception gap exists between WKAR Lansing and WXSP Grand Rapids, meaning that a handoff between those two stations was unlikely to succeed, which proved to be the case. These observations present a realistic depiction of predicted and observed "reception holes" and/or areas of intermittent service. A clear challenge to establishing a national datacasting service, conditions of this sort present the realistic expectation that densification of transmitters will be a necessary aspect of constructing a viable national datacasting service for launch.

Broadcast stations across the U.S. present a vast array of facilities exhibiting a wide range of emission characteristics that result from several generations of regulatory allocation and allotment practices focused on TV Household coverage maximization and intermodulation minimization design and operation objectives. A clear case for Broadcast CORE network development thus can be made to address location-specific, mobile reception measurement and potential AI optimization among a changing pool of emission sources.

VI. AL-FEC PAYLOAD PROCESSING AND ROUTING

The data delivery topology utilized in the phase 2.0 drive test is shown in Figure VI.1. The configuration shows the end-to-end content delivery, including the various technology touchpoint interfaces, required for content delivery to the ATSC 3.0 broadcast stations.

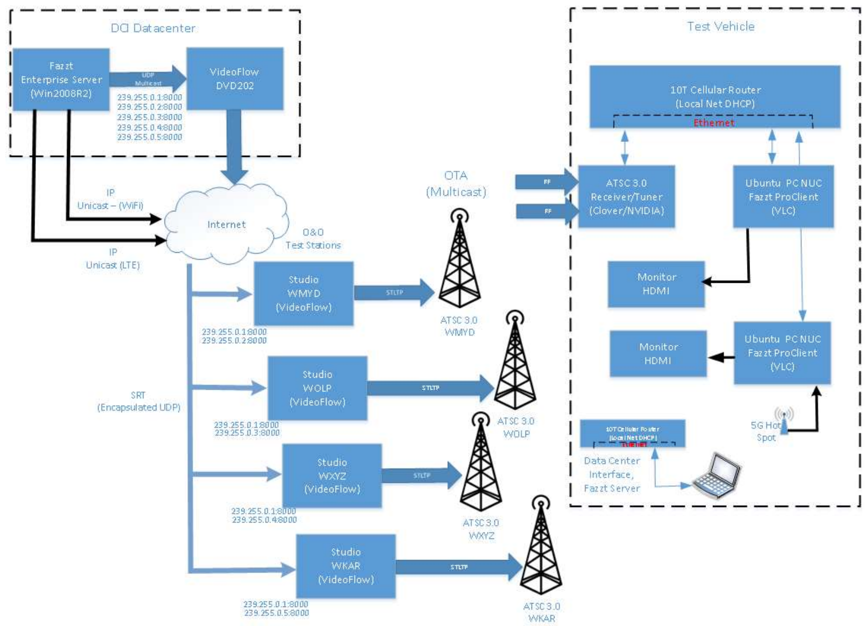


Figure V1.1 Phase 2 test configuration

Content originated from the Alchemedia SG's ATSC 3.0 lab in Washington, DC. This was the access point to the public internet for all file and streaming data that entered the system. The lab hosted the KenCast FAZZT Enterprise Server and the VideoFlow DVA-202 content transport unit, to provide secure and robust content delivery.

The KenCast Enterprise server software provides Application Layer Forward Error Correction (AL-FEC) to ensure data delivery integrity for file and streaming content. Applying AL-FEC to content allows for reconstruction of original data when it is received, as it may experience packet loss, packet delay, and packet order hierarchy effects that would impair reception without AL-FEC. The KenCast server outputs content, via Ethernet, as a Class D IP (Internet Protocol) Multicast channel. Multiple multicast channels were used in this trial.

- Note: The use of multicast is restricted to closed or private networks where the broadcast data may be controlled by joins to the stream, thereby preventing thundering herds of content replication that would result in an open Internet connection.
- The delivery of multicast streams to each studio was provided using a VideoFlow DVA-202 transport unit. A total of 5 VideoFlow units were used in this test. The DVA-202 provides an SRT (Secure Reliable Transport) tunnel(s) to encapsulate the multicast streams for delivery via the Internet to each of the studio facilities participating in this test.

For the test, the original bandwidth, of the NRT/PLP was assumed to be 2.7Mbps. This would be sufficient to send files, and to delivery live video streaming; however, due to constraints of service delivery at the live stations, the allowable bandwidth was limited to 1Mbps.

- Note: With an available bandwidth of 2.7Mbps large files could be delivered in reasonable timeframes.

- Example: a 1 GB file delivered at 2.7Mbps would take 1 hour 40 minutes to deliver. The same file delivered at 1Mbps would take 2 hours and 13 minutes to deliver.

In order to overcome this limitation of reduced bandwidth, e.g. 1Mbps vs 2.7Mbps, file delivery was implemented using the KenCast feature of Split Channels. This feature allows for the same content to be delivered on different multicast addresses to the multiple transmission sites. With each tower receiving data at 1Mbps, and on a different multicast address, there was no violation of the NRT/PLP bandwidth limit at any one tower. With this transmission topology, as the vehicle was travelling, when the ATSC 3.0 receiver was receiving signal from two towers, the multiple stream data was decoded by the FAZZT client and added together; thereby, this feature effectively increases the throughput of the transmission by a factor of 2.

The multicast data was delivered to each of the remote VideoFlow transport units, and ingested into the ROUTE stream for each of the participating stations, and then transmitted out over the air. The following is a description of the receiving system used to collect and decode the delivered data.

VII. Receiver Setup

A. Hardware

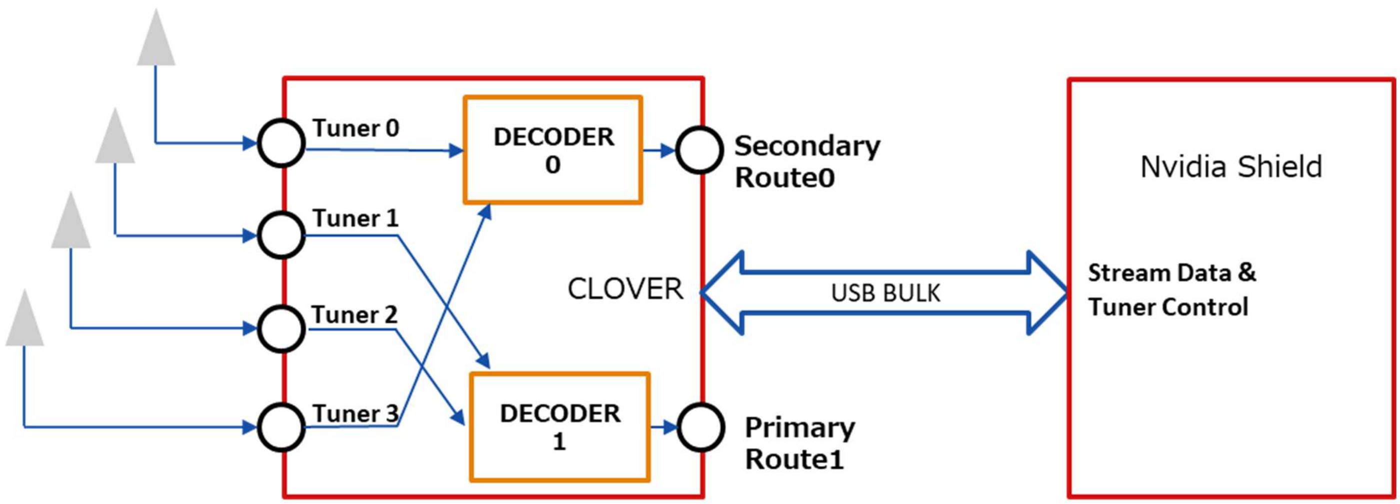


Figure VII.1 Sony Clover and Nvidia Shield configuration

B. Software

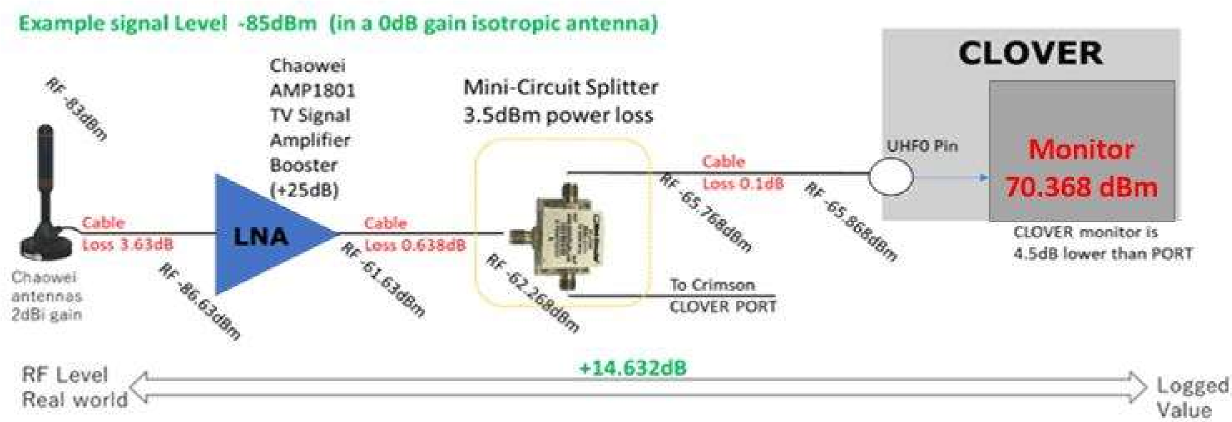


Figure VII.2 Block diagram of receiver tuner with signal levels

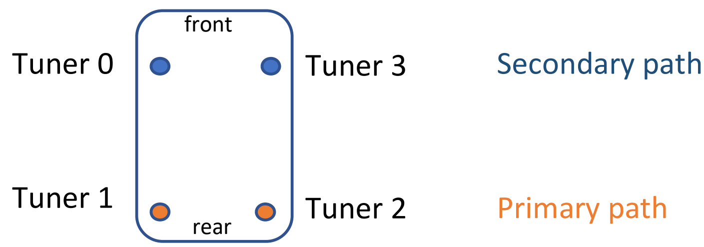


Figure VII.3 Antenna placement on vehicle

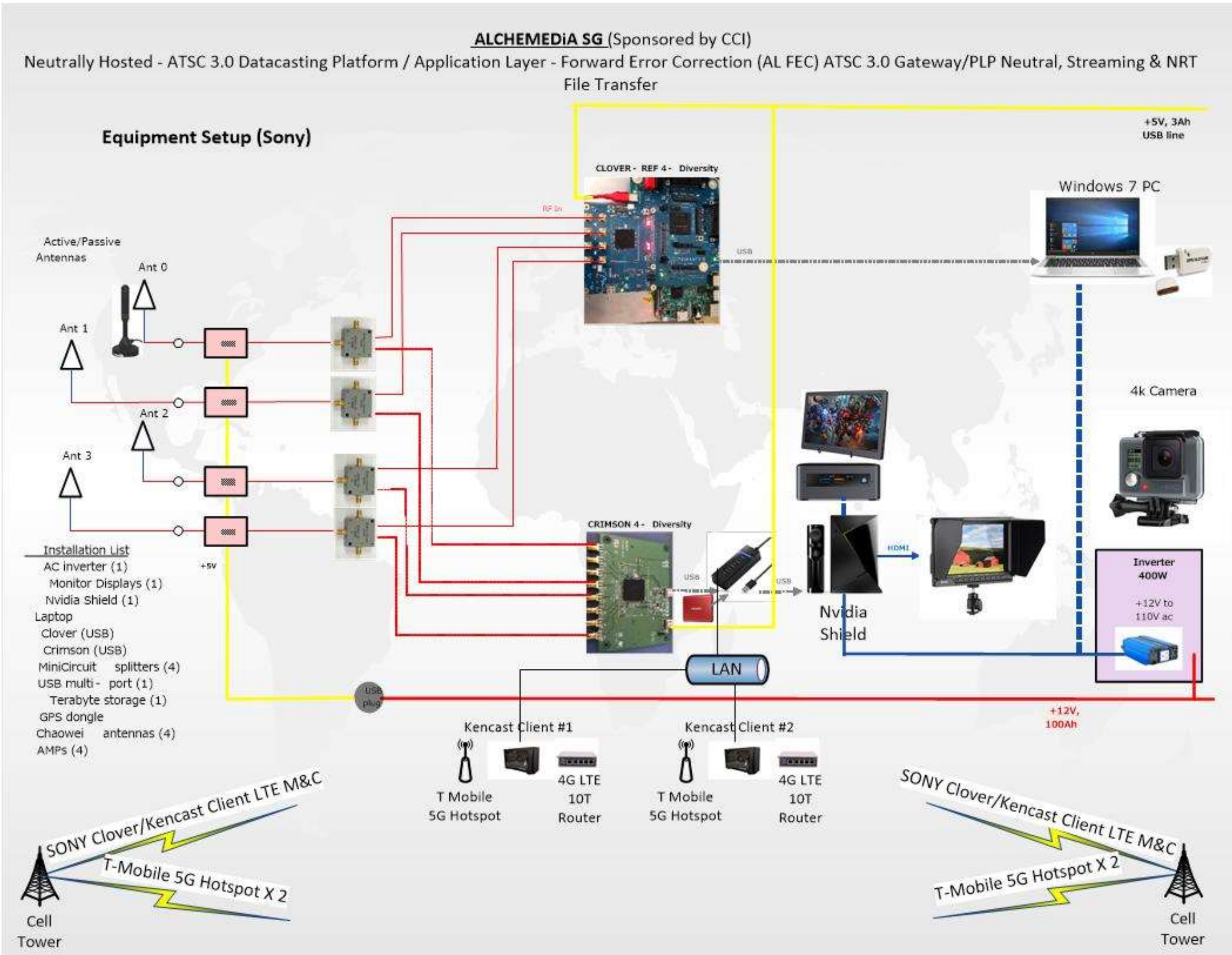


Figure VII.4 Test vehicle configuration

VIII. PAYLOAD AND GATEWAY CONFIGURATION

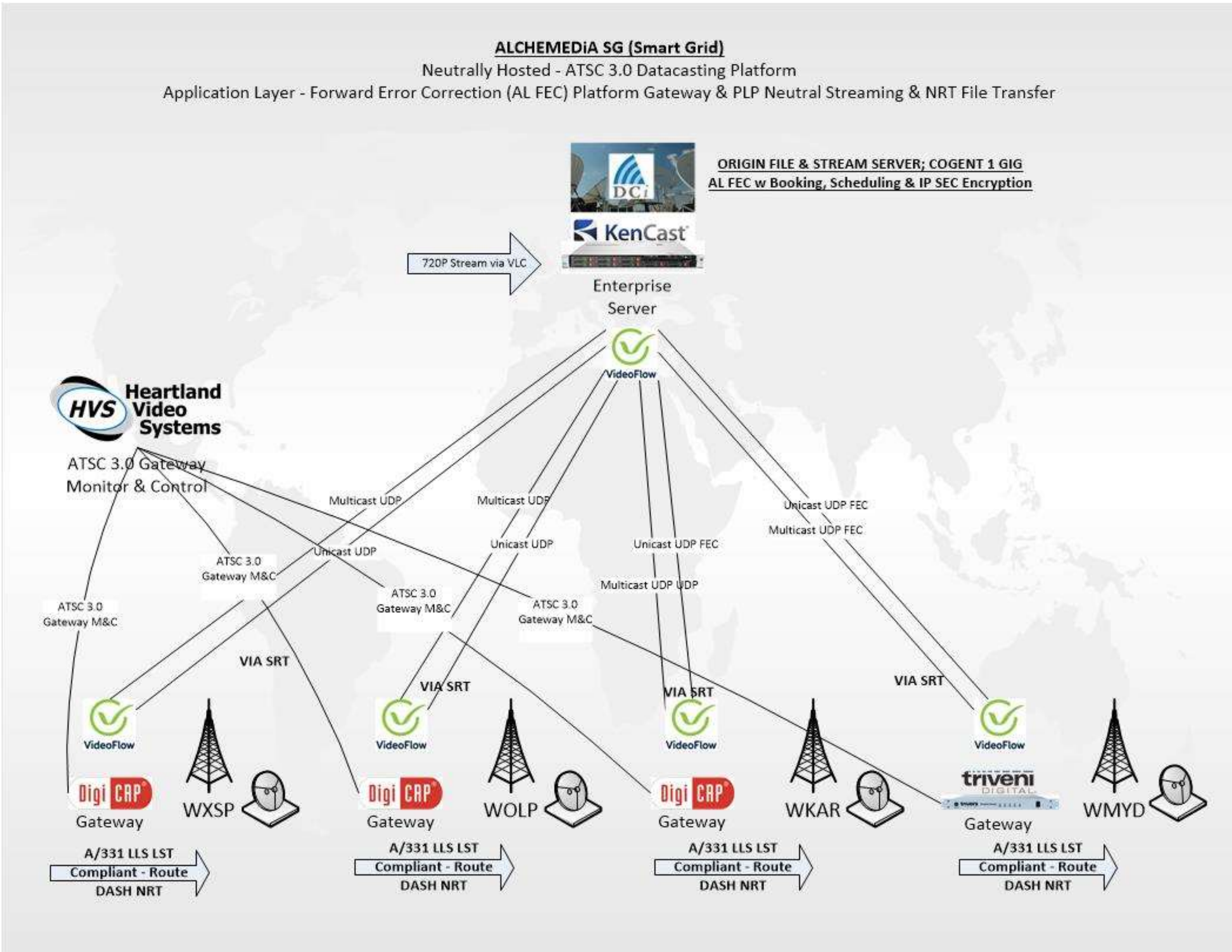


Figure VIII.1 Payload and Gateway Configuration

IX. RESULTS

A. Service Handoff

The transition regions between markets have some dropouts as shown by the blank areas within Figure IX.1 below depicting the overlay of primary and secondary emission reception data.

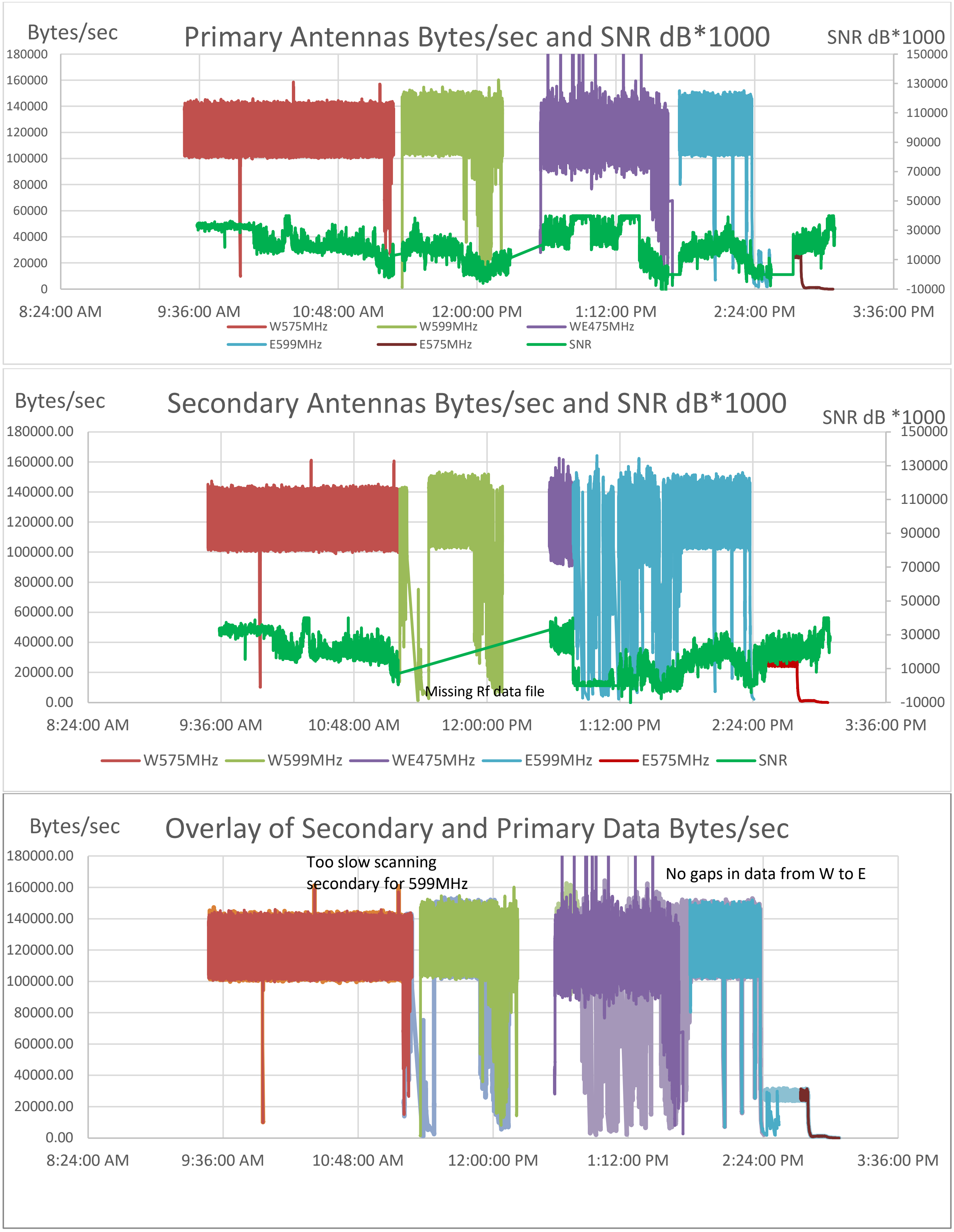


Figure IX.1 Lake Michigan to Canada handover points

B. NRT File Delivery

Nominal observations about NRT file transfer best practices have generally followed the logic presented in the previous Sony test results [4] "In addition to these factors, consider the number of times a file could carousel, which" is like a "slideshow" cycling through different elements such as photos, videos, or text. "At least two carousels would be the minimum as vehicle receivers would need time to tune in, likely in the middle of the 1st delivery. The 2nd delivery would ensure the entire file is captured if there was tune in time or other latencies to picking put the file."

The file delivery verification certificates in Figure IX.3 below demonstrate successful addressable, (non-carousel type) continuous FEC enabled file delivery without a return channel.

File Transmission Acknowledgments

File:	E:\Phase2\8G_TheColors-of-the-Ocean.mp4
Name:	8G_TheColors-of-the-Ocean.mp4
Transmission ID:	3063202704
Transmission UUID:	1721FFB9-9D43-4D40-9315-B5CE54271C6B
Transmission Count:	3
Packets:	5806080
Sent Packets:	6832369 (total including retransmissions)
Last Transmission End:	
Acknowledgment Report Mode:	Report always

Receive Sites which have not reported (0):
Receive Sites which reported (2)

Show All Reports | Refresh | Back | Help

Receive Sites: Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173241	Validated	2/25/2022 4:37:20 PM

Show All Reports | Refresh | Back | Help

File Transmission Acknowledgments

File:	E:\Phase2\158M_bbb_1080p_c.ts
Name:	158M_bbb_1080p_c.ts
Transmission ID:	2111682437
Transmission UUID:	B2836673-2E91-4988-9A56-FC2687A9C2C9
Transmission Count:	1
Packets:	1872003
Sent Packets:	561339 (total including retransmissions)
Last Transmission End:	2/24/2022 4:23:03 PM
Acknowledgment Report Mode:	Report always

Receive Sites which have not reported (1): 173225
Receive Sites which reported (2)

Show All Reports | Refresh | Back | Help

Receive Sites: Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173240	Complete	2/24/2022 4:23:18 PM
173241	Complete	2/24/2022 4:23:30 PM

Show All Reports | Refresh | Back | Help

File Transmission Acknowledgments

File:	E:\Phase2\157M_4K30minTestCardCalibration.mp4
Name:	157M_4K30minTestCardCalibration.mp4
Transmission ID:	268832503
Transmission UUID:	7F28DF7F-05CF-4F35-A663-89EEB46BAA38
Transmission Count:	1
Packets:	1857890
Sent Packets:	1538120 (total including retransmissions)
Last Transmission End:	2/24/2022 12:57:34 PM
Acknowledgment Report Mode:	Report always

Receive Sites which have not reported (1): 173225
Receive Sites which reported (2)

Show All Reports | Refresh | Back | Help

Receive Sites: Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173240	Complete	2/24/2022 1:00:14 PM
173241	Complete	2/24/2022 1:00:25 PM

Show All Reports | Refresh | Back | Help

File Transmission Acknowledgments

File:	E:\Phase2\936M_COSTA_RICA_4K.mp4
Name:	936M_COSTA_RICA_4K.mp4
Transmission ID:	1190257470
Transmission UUID:	ABA9C346-BDFC-4CA5-B658-335E838EE52A
Transmission Count:	1
Packets:	11040012
Sent Packets:	3655080 (total including retransmissions)
Last Transmission End:	2/24/2022 3:55:33 PM
Acknowledgment Report Mode:	Report always

Receive Sites which have not reported (1): 173225
Receive Sites which reported (4)

Show All Reports | Refresh | Back | Help

Receive Sites: Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173240	Complete	2/24/2022 3:58:05 PM
173241	Complete	2/24/2022 3:58:22 PM

Show All Reports | Refresh | Back | Help

File Transmission Acknowledgments

File:	E:\Phase2\216M_Sony4KAnotherWorld.mp4
Name:	216M_Sony4KAnotherWorld.mp4
Transmission ID:	3033107404
Transmission UUID:	EF04EAFD-23E6-4718-A440-D618899E7956
Transmission Count:	3
Packets:	2557203
Sent Packets:	1065575 (total including retransmissions)
Last Transmission End:	2/24/2022 5:19:58 PM
Acknowledgment Report Mode:	Report always

Receive Sites which have not reported (1): 173225
Receive Sites which reported (4)

Show All Reports | Refresh | Back | Help

Receive Sites: | Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173240	Complete	2/24/2022 5:06:02 PM
173241	Complete	2/24/2022 5:22:57 PM

Show All Reports | Refresh | Back | Help

FEC Details:
FEC Block size: 240x240 source packets
Sending is interleaved.

Figure IX.1: File transmission acknowledgements

C. Larger File Size

1. While testing small file sizes enables tracking of packet loss locations, it is not a likely scenario for business use-case.
2. Phase 2 testing further demonstrated addressable AL-FEC distribution and reception of larger file sizes via ATSC 3.0

X. KENCAST FAZZT SERVER-SIDE AND CLIENT-SIDE WORKFLOW FOR MICHIGAN TESTS

Kencast FAZZT server-side file workflow:

- The FAZZT server was configured with one master channel (Split Channel) that fed into four individual multicast channels. These multicast channels correspond to the four different towers and were configured to output at 1Mbps for the test.

- The FAZZT server was also configured with a collection of transmission modes corresponding to various parameters (encoding configuration, FEC percentage, compression, etc) that can be applied to individual deliveries.
  In the case of this test the transmission mode that was used was setup to use 1600% Fazzt Continuous FEC to deliver the files. This was done since the expected loss was only predicted and we had the ability to manually abort the transmission once we saw that the client received

110% worth of FEC packets (103% is typically required to decode a file a healthy buffer was included).

- Once the server was instructed to deliver a piece of content (or collection of) with the transmission mode / parameters defined above the following happened:

  - The server analyzed the content and started generating Continuous FEC packets. The Continuous FEC packets were generated over a block size of 240x240 source packets. Continuous FEC Packets generated from different blocks are interleaved when sent out on the Split Channel – one packet from block 1, one packet from block 2, ….

  - The Split Channel evenly divides the packets on the four multicast channels as configured.

  - Packets hit the wire from the multicast channels

  - After the server sent out all 1600% of the packets (did not happen in this case) OR after the transmission was manually aborted by the tester (happened in this case), once the client received enough data the following occurs:

    1. The server waits a defined time (in the transmission mode) for reports to come back from clients and log the results (success or failure). For success no packet loss information is provided.
    2. If the clients reports that it needs additional data to reconstruct the file (see below) more Continuous FEC data is potentially transmitted (according to rules configured in the transmission mode).
    3. Cycle repeats (go back to step 1) as configured in the transmission mode.

Kencast FAZZT client side file workflow:

- The Fazzt client was configured to listen to all four multicast channels the server was sending corresponding to the four towers.

- Once Fazzt Professional (PC) client detects a Fazzt packet on any of the channels it is tuned to (IGMP tune) it creates a file receive transmission with the transmission ID corresponding to the information in the packet.

- Packets are written to a temporary file ([transmissionID.kdt] as they are coming in.

- Once either all packets of the transmission are sent OR no data in the transmission is received for 2 minutes the clients close the transmission and start the post processing process.

- The post processing process performs FEC decoding to reconstruct the original file based on the data available in the .kdt file.
  - As a first step, the client can quickly check to see if additional data is needed and, if needed, report back how many packets are needed for each FEC block (defined above). The server would then send out additional data according to what is defined in the Transmission Mode.

  - Once enough packets are received for each FEC Block, the client proceeds to perform Continuous FEC decoding to reconstruct the original source file from the Continuous FEC packets.

  - The client reports back an ACK to the server

File Delivery: Benefits with Fazzt AL-FEC:

- Continuous FEC Eliminates wasteful carouselling of content that is necessary when no application level FEC is deployed.

- Continuous FEC enables clients to receive content from several sources/towers:

  - At the same time doubling the incoming data rate if receiving from two towers or tripling the incoming data rate if receiving from three towers.

  - Transition from one tower to another is seamless in that the towers do not need to be aligned in their content delivery cycle(E.g. can receive the last 50% of a transmission from two towers and still be able to reconstruct the file).

- Ability to loose the signal for an extended period of time. As long as a client receives Continuous FEC packets corresponding to 103% of the source file size it can reconstruct the data.

- AES-256 encryption is available.

- Addressing is available.

- Powerful prioritization (FIFO and real-time adjusting priority) capabilities.

Server side stream workflow specifics:

- Configuration:
  - Address: port to listen to for data stream
  - Time window: 1200 s
  - FEC percentage: 25%
  - Same multicast channel configured to go to all four towers (239.255.0.1:8000)

- The Fazzt server listens for incoming packets and applies Fazzt FEC over the time window specified and created 1/(1-(FEC percentage)/100) times packets [source packets and FEC packets]. For example, 50% Fazzt FEC results in doubling the stream bitrate and 25% Fazzt FEC configuration results in 33% additional data being sent out
- The Fazzt server outputs source stream packets and Fazzt FEC packets on a multicast channel reaching all towers

Client side stream workflow specifics:

- The Fazzt client was configured to listen to the one multicast channel the server was sending to reach all four towers.

- Once the Fazzt Professional (PC) client detected a Fazzt packet on the stream channel it opened up a stream receive transmission with the transmission ID corresponding to the information in the packet.

- Packets are stored in memory as they arrive. The memory buffer holds 1200 s worth of content (about 1GB worth of data in this case as the source stream was ~600 kbps).

- FEC repair is executed over the time window specified resulting in:

    - Source stream is delayed 1200 s before it is output to the specified address:port / interface on the client end.

    - Up to 400 s worth of missing data can be reconstructed every 1200 s over a moving time window.

- Introducing Fazzt FEC holds the promise of lowering Low Latency Forward Error Correction (LL-FEC) thereby increasing the available throughout for file delivery as Fazzt FEC operates over a large time window (files) while LL-FEC operates over single packets and needs to be more aggressive to correct for errors

Stream Delivery: Benefits with Fazzt:

- Fazzt FEC allows for extended packet drop scenarios.

- Fazzt FEC enables clients to receive content from several sources/towers:

    - At the same time increasing the chance of receiving the stream. Towers do not need to be in perfect sync.

    - Transition from one tower to another is seamless in that the towers do not need to be perfectly aligned in their content delivery cycle. E.g. in the above example the towers can be 400 s out of sync and the transition could be seamless.

- AES-256 encryption is available.

- Addressing is available.

XI. CONCLUSION

The Michigan Coast-to-Coast Data Delivery Drive Tests demonstrated that ATSC 3.0 technologies can be implemented now to deliver data over a wide area to moving vehicles reliably and with high throughput. They also showed that there are extensions to the ATSC 3.0 technologies with the potential to push throughput and reliability to even higher levels. The drive tests used a combination of off-the-shelf broadcast hardware with slightly modified software and prototype mobile receiving equipment that implemented diversity reception. Early tests only used data protocols already included in ATSC 3.0 standards, while the phase 2 test showed the benefits that could be achieved with more advanced forward error correction software that is available in the marketplace. All told, the tests showed that, in a matter of a few months, a quite effective system for reliable data distribution to mobile receivers could be set up using existing infrastructure of multiple television stations to cover an area measured in thousands of square miles.

The Alchemedia/Kencast design which employs FEC (Forward Error Correction) allows transmit and receive interplay to create a robust and reliable file and streaming delivery. The software overlay. with the use of a specially outfitted SUV employing the Sony clover receiver and Kencast patented Fazzt software, demonstrated the automation of machine managed effective file delivery across the 300-mile stretch of highway during the field tests. Additionally, a return channel was implemented with integration to the ATSC 3.0 transmission for monitoring, control and analytics.

XII. NEXT STEPS

This demonstration proves the technical case for a nation-wide datacasting service bringing addition revenues to broadcasters and additional services to their customers, utilizing an independent “neutral” managing entity. Business and use cases should incorporate additional testing with “densification” (often referred to as broadcast cellular) for additional robustness and expansion of coverage areas from each current ‘tall tower”; i.e., enhancement of existing Broadcaster tall tower infrastructure with mobile targeted small cell and/or single frequency network (SFN) development and deployment.
Further future activities include:

- Development of broadcast core enabled automation of simultaneous MFN/SFN channel discovery and reception

- Testing of various KenCast FEC configurations in various ATSC 3.0 physical layer configurations; i.e.,

    - 1) in the same PLP as a bandwidth optimized A/V mux distribution of streaming video and audio channels,
    - 2) with and without LDM configuration,
    - 3) comparison to current ATSC 3.0 RaptorQ FEC option,
    - 4) analysis of use case vs configuration variables; i.e., what specific payloads and use cases benefit for what specific configuration methods

- Employ machine learning for optimization of FEC controlled error correction and selection of “highest robustness” or “minimum delay” with regard to managing dynamic variation of location specific emission characteristics via ongoing, big data collection and analysis

- Enable an ARM compiled SDN Client for deployment over Nvidia Automotive infrastructure & framework

- Development of a neutrally hosted UI for registration, discovery, booking, scheduling and publication of file and streaming payloads

APPENDIX I: MICHIGAN DRIVE AND RECEPTION TEST RECAP

The first day of field testing, Feb. 23, 2022, was conducted from the garage facility of station WXYZ, in Southfield, MI. This test was to confirm the configuration and to transfer a file to the stationary vehicle from an indoor location. The second and third days of the drive test, Feb. 24 and 25, consisted of driving the I96 corridor between Detroit and Lansing, while sending files and live video (multicast file from DCI datacenter).

The drive route for phase 2.0 emulated the route taken in the phase 1.5 test. The origination point for each of the two-day drive testing was from the MGM Grand Casino in Detroit, MI following I-96 to Lansing, MI. The return trip endpoint each day was the garage facility located at station WXYZ, in Southfield, MI.

Figure 1 shows the drive route and modeling footprints for the transmission towers that data was received from during each drive test.

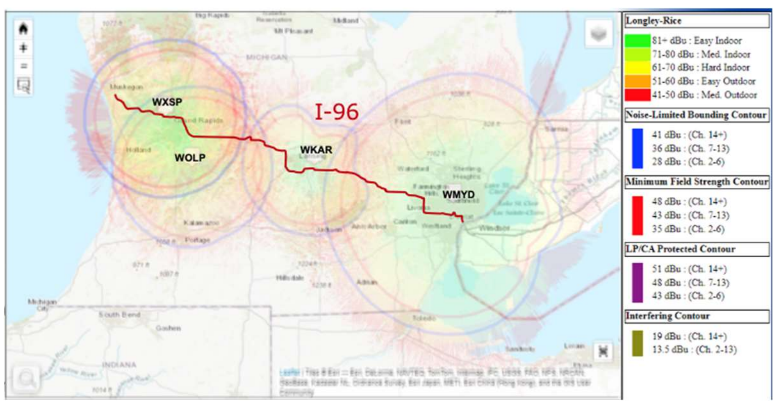


Figure 1. Tower Transmission Patterns

The vehicle, a Ford Expedition, was outfitted with four 4k/1080p Chaowei antennas with signal boosters. Figure 2 shows the external mounting.

Figure 2. Vehicle with External Antenna's

The interior of the car was configured with the receive site test-bed. The test-bed configuration is shown in figures 3 and 4.

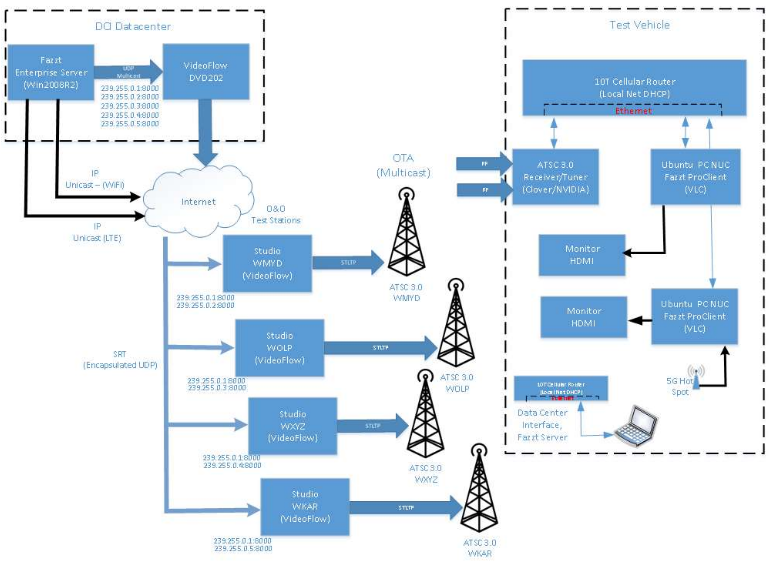


Figure 3. Receive Configuration in Vehicle

The receive test-bed allowed for remote command, configuration, and control to the necessary touchpoints in the vehicle and at the datacenter. This was implemented using 10T Solutions LTE (Long-Term Evolution) cellular router/switch modem. Two of these router modems were used for this test, each providing mobile Internet access.

- Note: Each of the LTE modems provided a unique local network, so that the file/stream delivery network was fully segregated from the KenCast server and VideoFlow control interface network.

The primary system provided remote access for the Clover receiver and the NVIDIA shield decoder. This unit provided an in-vehicle local network connecting the NVDIA shield ATSC 3.0 decoder to the dual KenCast Fazzt clients – each Fazzt client was running on an Intel NUC (Next Unit of Computing) mini PC, running Ubuntu 20.04 OS (Operating System). This system provided the signal flow path for the decoded NRT/PLP output data (the multicast file and live stream data) that was subsequently decoded by the two Fazzt clients. The second LTE router modem was used to connect a laptop to the datacenter for interface with the KenCast server and the VideoFlow transport unit. The primary LTE network is shown, as tested, in the following figure.

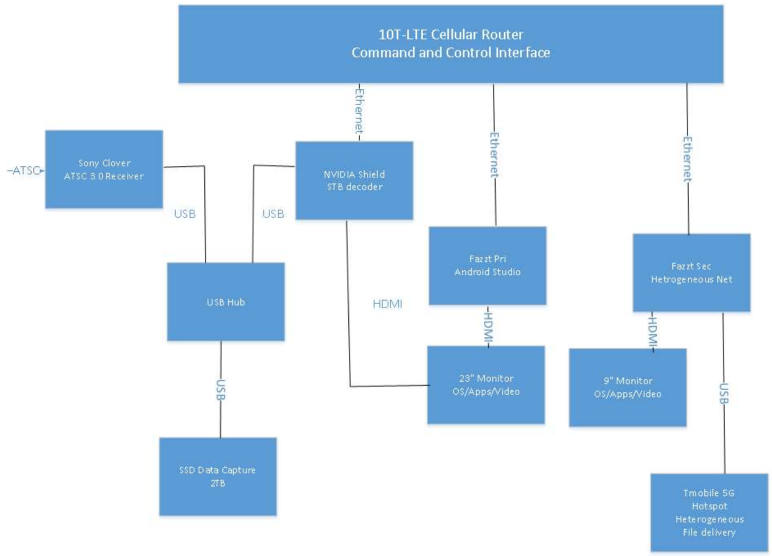


Figure 4. In Vehicle Network

The following figures show the test-bed with monitoring and reception interfaces.

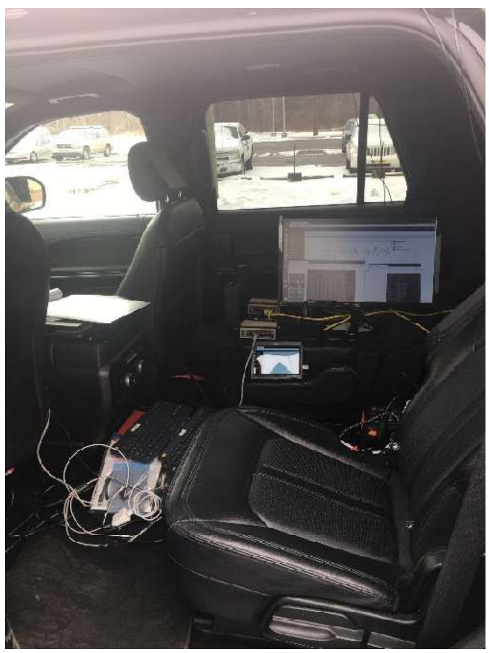


Figure 5. Vehicle Test-Bed Monitoring

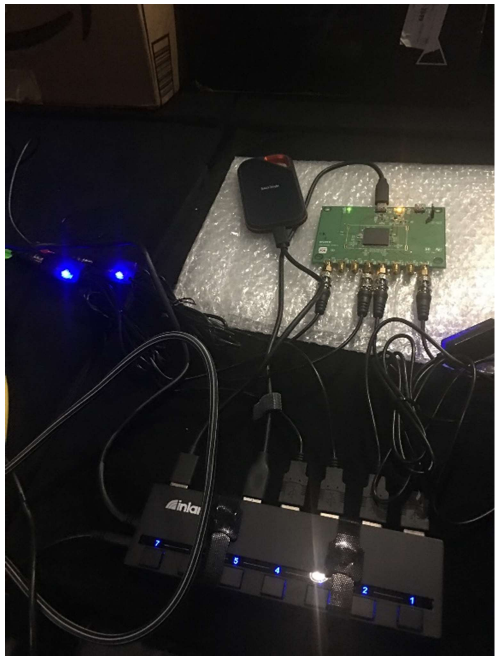


Figure 6. Clover Receiver and NVIDIA Shield Decoder

XIII. File Delivery

The first day of the test, Feb. 23, was to deliver a large file to the parked vehicle. With the vehicle test-bed powered by main power at the garage facility of station WXYZ.

The content, that was 158MB (Million Bytes), was the open source movie “Big Buck Bunny”. The receive conformation from the Fazzt client is shown below.

Rx Stop Time	Server ID	Channel Handle	Transmission ID	Transmission Status	File Name	Transmission Packet Count	Lost Packet Count	Main File
2022-02-23 15:22:00	660243	1000000	878099931	Validated	bbb_1080p_c.ts	125440	2	/var/fazzt/bbb_1080p_c.ts

Figure 2. First Day Garage Delivery

-Note: Two NUC computers were configured with Ubuntu 20.04, Linux OS. A KenCast Fazzt client was loaded on each of these devices. The primary client was Fazzt ID 173240, and the secondary client was Fazzt ID 173241. These enumerated client license file ID’s are the mechanism used to implement targeting of content. Content may be targeted for delivery to a group of ID’s, or segmented to a single ID. Each Fazzt client in a controlled network is anchored to its KenCast Enterprise server, and may only receive content from this origination server. The originating server, via ID, controls the delivery of content to the intended ID, or group of ID’s.

The second day of the test, Feb. 24, was to deliver large files to the vehicle in motion along the drive path from Detroit to Lansing roundtrip. The following are the files that were confirmed for delivery.

These files were delivered using the KenCast Fazzt AL-FEC feature “Continuous FEC”. This allows for the transmission to only contain correction packets and no content. Each transmission was sent with 1600% FEC; however, when the receiver acknowledged that 110% of the file had been the delivered, the transmission was manually stopped, and the file was completely delivered. Note: This is currently a manual process; however, this will be an automated process in the next release of the Fazzt product. The current release version is 10.0.1.

File Transmission Acknowledgments

File: E:\Phase2\157M_4K30minTestCardCalibration.mp4
Name: 157M_4K30minTestCardCalibration.mp4
Transmission ID: 268832503
Transmission UUID: 7F28DF7F-05CF-4F35-A663-89EEB46BAA38
Transmission Count: 1
Packets: 1857890
Sent Packets: 1538120 (total including retransmissions)
Last Transmission End: 2/24/2022 12:57:34 PM
Acknowledgment Report Mode: Report always

Receive Sites which have not reported (1): 173225
Receive Sites which reported (2)

Show All Reports | Refresh | Back | Help

Receive Sites: [ ] Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173240	Complete	2/24/2022 1:00:14 PM
173241	Complete	2/24/2022 1:00:25 PM

Show All Reports | Refresh | Back | Help

Figure 3. 157MB - Test Card Calibration

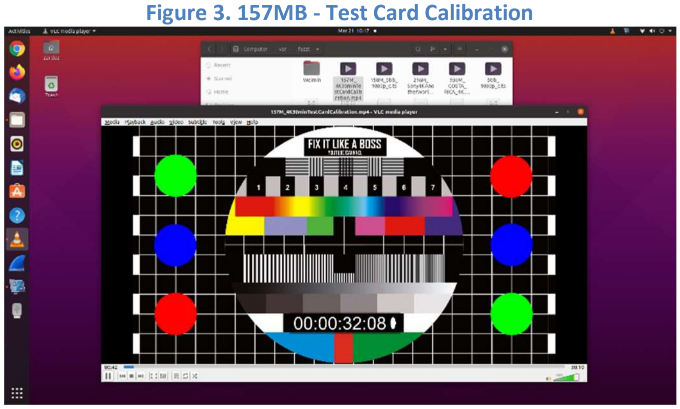


Figure 8. Test Card Calibration - Playing via VLC on Client

File Transmission Acknowledgments

File: E:\Phase2\936M_COSTA_RICA_4K.mp4
Name: 936M_COSTA_RICA_4K.mp4
Transmission ID: 1190257470
Transmission UUID: ABA9C346-BDFC-4CA5-B658-335E838EE52A
Transmission Count: 1
Packets: 11040012
Sent Packets: 3655080 (total including retransmissions)
Last Transmission End: 2/24/2022 3:55:33 PM
Acknowledgment Report Mode: Report always

Receive Sites which have not reported (1): 173225
Receive Sites which reported (4)

Show All Reports | Refresh | Back | Help

Receive Sites: [ ] Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173240	Complete	2/24/2022 3:58:05 PM
173241	Complete	2/24/2022 3:58:22 PM

Show All Reports | Refresh | Back | Help

Figure9. Costa Rica 4K Video

File Transmission Acknowledgments

File: E:\Phase2\8G_TheColors-of-the-Ocean.mp4
Name: 8G_TheColors-of-the-Ocean.mp4
Transmission ID: 3063202704
Transmission UUID: 1721FFB9-9D43-4D40-9315-B5CE54271C6B
Transmission Count: 3
Packets: 5806080
Sent Packets: 6832369 (total including retransmissions)
Last Transmission End:
Acknowledgment Report Mode: Report always

Receive Sites which have not reported (0):
Receive Sites which reported (2)

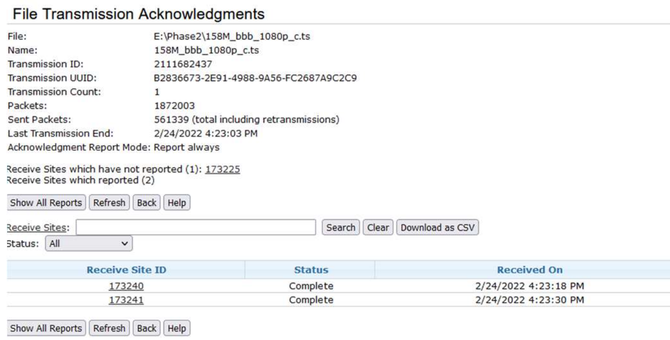
Show All Reports | Refresh | Back | Help

Receive Sites: [ ] Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173241	Validated	2/25/2022 4:37:20 PM

Show All Reports | Refresh | Back | Help

Figure 10. 8GB File The Colors of the Ocean



File Transmission Acknowledgments

File:	E:\Phase2\158M_bbb_1080p_c.ts
Name:	158M_bbb_1080p_c.ts
Transmission ID:	2111682437
Transmission UUID:	B2836673-2E91-4988-9A56-FC2687A9C2C9
Transmission Count:	1
Packets:	1872003
Sent Packets:	561339 (total including retransmissions)
Last Transmission End:	2/24/2022 4:23:03 PM
Acknowledgment Report Mode:	Report always

Receive Sites which have not reported (1): 173225
Receive Sites which reported (2)

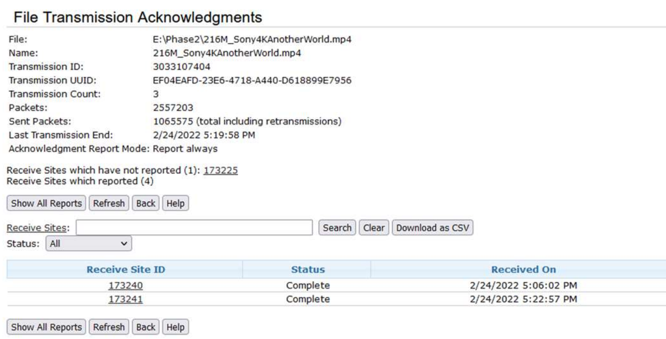
Show All Reports | Refresh | Back | Help

Receive Sites: Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173240	Complete	2/24/2022 4:23:18 PM
173241	Complete	2/24/2022 4:23:30 PM

Show All Reports | Refresh | Back | Help

Figure 1. Big Buck Bunny Movie File



File Transmission Acknowledgments

File:	E:\Phase2\216M_Sony4KAnotherWorld.mp4
Name:	216M_Sony4KAnotherWorld.mp4
Transmission ID:	3033107404
Transmission UUID:	EF04EAFD-23E6-4718-A440-D618899E7956
Transmission Count:	3
Packets:	2557203
Sent Packets:	1065575 (total including retransmissions)
Last Transmission End:	2/24/2022 5:19:58 PM
Acknowledgment Report Mode:	Report always

Receive Sites which have not reported (1): 173225
Receive Sites which reported (4)

Show All Reports | Refresh | Back | Help

Receive Sites: Search | Clear | Download as CSV
Status: All

Receive Site ID	Status	Received On
173240	Complete	2/24/2022 5:06:02 PM
173241	Complete	2/24/2022 5:22:57 PM

Show All Reports | Refresh | Back | Help

Figure 2. 216MB File 4K Another World

These files were received in the time and bandwidth constraints of the drive test on Feb. 24. With the bandwidth constraint of 1Mbps, the time to deliver larger files 100GB, or 200GB was not available within the roundtrip time frame. When the advantage of the Split/Join increasing the deliverable bandwidth to 2Mbps, as shown in figure 16, the delivery time to transfer a 200GB file exceeded the total drive time.

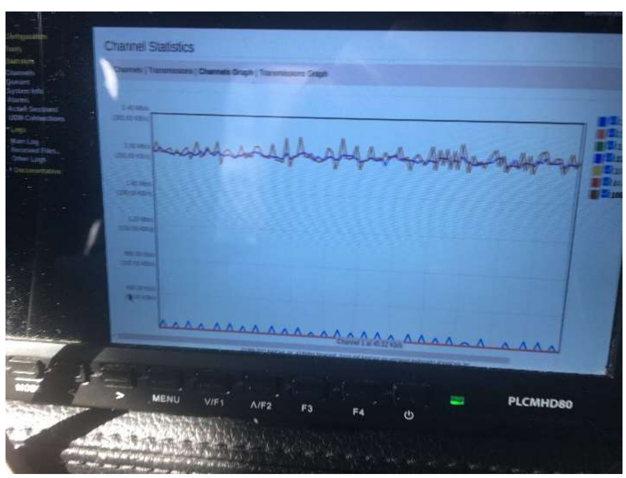


Figure 3. Joined Channel Bandwidth in Vehicle

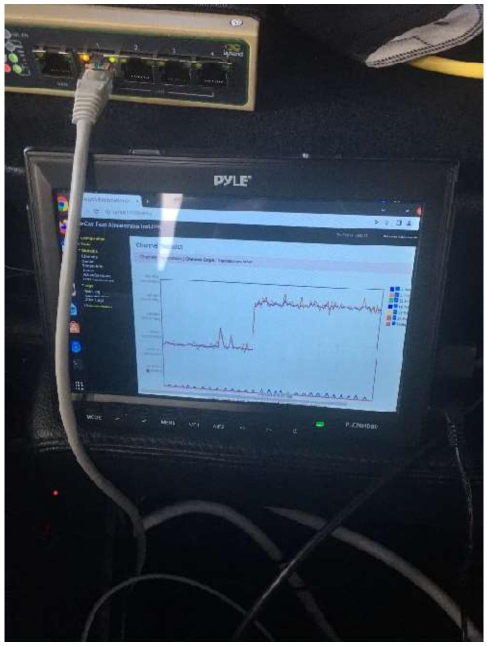


Figure 4. Join Channels with Reception from Second Tower

Figure 16 shows the joined channel bandwidth that was available when multiple tower locations were being received. Figure 17 shows the transition from 1Mbps to 2Mbps when join channel reception is available, i.e. the bandwidth doubles. Note: The split/join channel feature is only available for the delivery of file data, and not for streaming content. The final drive test was spent on steaming content and working with the T-Mobile 5G hotspot as an alternate file delivery option.

LIVE STREAMING

The drive testing on Feb. 25 was dedicated to streaming live video. Note: The KenCast system does not track live stream data as it is played out live on the receiver. There are captured (via cell phone) mpeg files of the live streams played during this portion of the test. The figures shown below are image captures of the live stream as it played with the vehicle on the drive path between Detroit and Lansing, MI, on I-96.

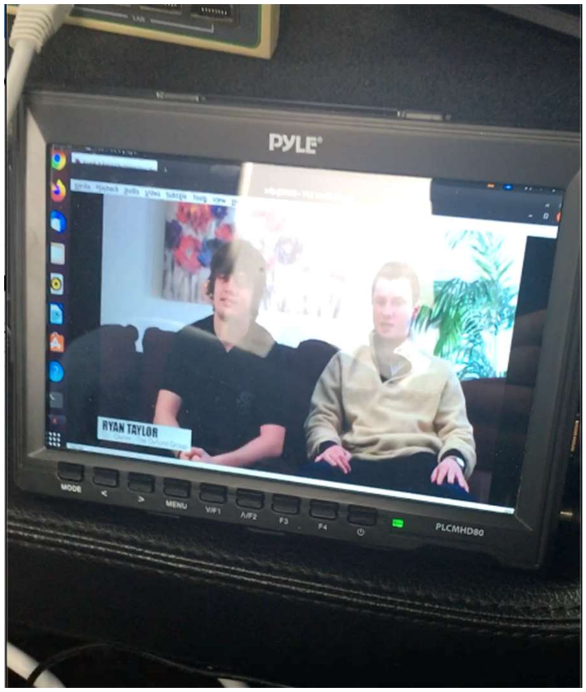


Figure 5. Live Video Play - Stock KenCast Content

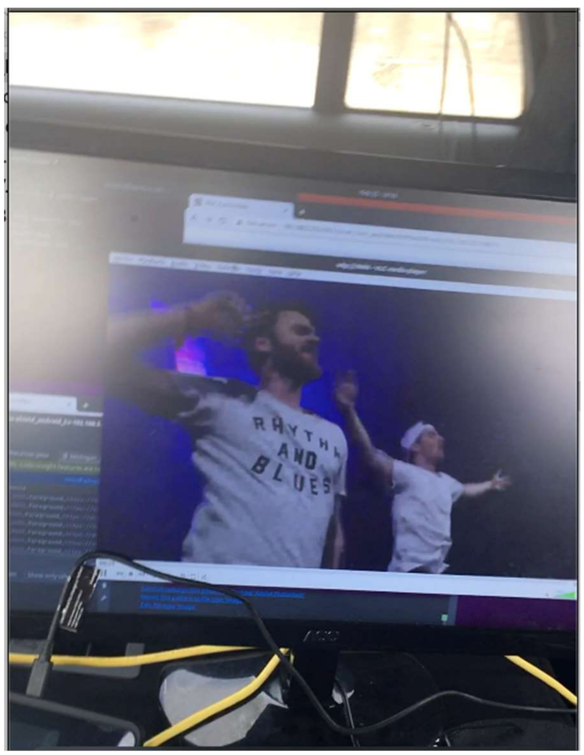


Figure 4. Live Video Play - Stock KenCast Content

For the duration of the drive the video from the DCI datacenter, the video file was set to repeat, i.e. loop, and it played continuously. The file was constant with the exception of an outage caused be a crash of the clover diversity receiver. When the receiver was restored, video reception was restored and video was available on the receive client.

A. Heterogenous Networking

As an additional option for the ability to send larger data files, it was proposed, for the drive test, to use a T-Mobile 5G hotspot, so the KenCast system would receive more data simultaneously. The idea was to have a way to access higher bandwidth, as the 5G hotspot is advertised to provide 70 to 100Mbps of data deliver; however, the live drive test showed that the received data from the hotspot was never greater than 5Mbps. With this delivery speed, the proposed 200GB file could not be delivered within the timeframe of the roundtrip drive from Detroit and Lansing. Further analysis and testing with the carrier will need to be in place to verify coverage and expected throughput.

Note: Prior to the physical drive test in a test lab environment, the 5G hotspot was shown to provide throughput at 85Mbps. This configuration, in a different physical location from the drive path in Michigan, confirmed that an Internet connection to the KenCast server was available, and files could be delivered. More testing on this will be conducted prior to any further use of this hotspot.

APPENDIX II: GLOSSARY

- A331 – An ATSC 3.0 standard related to Signaling, Delivery, Synchronization and Error Protection
- AI – Artificial Intelligence
- ALC – Asynchronous Layered Coding
- AL-FEC – Application Layer Forward Error Correction
- ALP – ATSC Link-Layer Protocol
- ATSC – Advanced Television Systems Committee
- ATSSS: Access Traffic Steering, Switching and Splitting (ATSSS); MPTCP is now an integral part of 5G mobile networks as a standard feature of 3GPP Release 16. The 3GPP 5G mobile core features Access Traffic Steering, Switching and Splitting (ATSSS) and has officially standardized on MPTCP as a foundational capability. ATSSS allows operators to direct traffic through certain access networks, switch traffic across access networks and aggregate traffic over multiple access networks. Continuous user experience with higher throughout is delivered as the mobile device moves around and among access network technologies such as 5G NR, Wi-Fi and others.
- BSID – Broadcast Stream ID
- Carousel – “slideshow” functionality to transmit in recurring sequence video, photo, text, or other types of data files
- FEC – Forward Error Correction is a method of obtaining error control in data transmission in which the source (transmitter) sends redundant data with no retransmissions, and the destination (receiver) applies the additional data to correct errors to the extent possible, accepting only the portion of the data that contains no apparent errors after correction

- Kencast Fazzt – The basic components of Fazzt are a transmitting server, one or more receiving clients, and an end-to-end management system that monitors and actively optimizes the performance of the network. High reliability is achieved through KenCast's Fazzt Forward Error Correction (FEC) technology, which enables each receive site to recover missing packets without requiring retransmissions by the host.
- LCT – Layered Coding Transport
- LLS – Low Level Signaling as it relates to the ATSC 3.0 standard
- LNA – Low Noise Amplifier
- MFN – Multi-Frequency Network (MFN) is a network in which multiple radio frequencies (or RF channels) are used to transmit media content
- ML – Machine Learning, which is a subset of Artificial Intelligence
- MOD-COD – MODulation and CODing
- MDUDP: Multipath Multimedia Transport Protocol over Overlay Network (MPUDP); MPUDP is a session-based protocol that allows applications to transmit and distribute data over multiple flows. The MPUDP multipath framework forms an overlay network and consists of three logical entities: the user agent, the relay controller, and the relay server. The relay controller functionality is to manage the overlay network topology. The Relay server forwards data packets to the next hop based on a local routing table. When the sender (user agent) initializes a transmission VOLUME 9, 2021 66821 A. Hodroj et al.: Survey on Video Streaming in Multipath and Multihomed Overlay Networks FIGURE 2. Content delivery networks (CDNs). session, it requests from the relay controller to allocate multiple paths which allow the sender to select paths with minimum utilization of load weight to transmit the packet. In summary, the overlay network allows path quality evaluation and dynamic data distribution which maximize path utilization.
- NEXTGEN TV – Industry branding for the ATSC 3.0 digital standard
- PLP – Physical Layer Pipe
- Raptor Q – The RaptorQ code defined in IETF RFC 6330 is specified as a part of the Next Gen TV (ATSC 3.0) standard to enable high quality broadcast video streaming and efficient and reliable broadcast file delivery.
- ROUTE – Real-time Object delivery over Unidirectional Transport
- ROUTE/DASH – is an IP streaming-based system for delivery of broadcast and broadband services, combining ROUTE with MPEG Digital Adaptive Streaming over HTTP (DASH)
- SFN – A single-frequency network or SFN is a broadcast network in which several transmitters simultaneously send the same signal over the same frequency channel to provide service to a common area
- SLT – Service List Table
- TOI – Transport Object Identifier
- TSI – Transport Session Identifier
- UDP – User Datagram Protocol is uni-directional, as opposed to TCP, which is bidirectional, thereby providing low latency.

REFERENCES

[1] ATSC 3.0 Physical Layer Protocol, ATSC A/322, January 2021.

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[3] ATSC Interactive Content, ATSC A/344, January 2021
[4] ATSC 3.0 Automotive Field Tests, https://www.sony.com/content/dam/sony/landing-pages/whitepaper-atsc30_automotive_field_tests_.pdf