ATSC 3.0 File Delivery to Multiple Markets

Luke Fay and Graham Clift (Sony Electronics, Inc.)

***Abstract*— ATSC 3.0 offers a large variety of innovative use-cases using multicast delivery. In addition to high bitrate television broadcasts to stationary televisions, ATSC 3.0 also supports multicast file delivery to the automotive industry since very robust physical layer parameters can be selected and therefore reliable high-speed reception is now possible. This paper investigates how the ATSC 3.0 suite of standards can support multiple frequency networks, provides an example PHY configuration and required signaling for automotive file delivery while not interfering with media services, tests the configuration in three markets (across the state of Michigan, from Detroit to Lansing to Grand Rapids), and shows compelling evidence that NEXTGEN TV can support automotive services.**

***Index Terms*—ATSC 3.0, NEXTGEN TV, automotive, field tests, multiple frequency networks, digital terrestrial broadcasting.**

I. Introduction

One of the many innovative use cases of NEXTGEN TV is in the automotive industry, particularly the use case in which files are delivered to moving vehicles while still broadcasting linear television services to stationary devices. The ATSC 3.0 protocol stack was built to ensure the file delivery use case is possible; in fact, it can be considered that all media transmission is by file delivery, with some files carrying real time media and others transporting non-real time (NRT) data. This paper will look at NRT file delivery in the runtime environment, as described in ATSC A/331 and A/344, and at how broadcasters can work together to provide multicast delivery of these files as a service to multiple markets. The work was conducted by Sony Semiconductor Solutions (SSS), Sony Home Entertainment and Sound products of America (SHES-A), Heartland Video Systems, Crown Castle International, E.W. Scripps Broadcasting's WMYD in Detroit, Michigan State University's WKAR in East Lansing, and Nexstar's WXSP and WOLP in Grand Rapids, all Michigan. Proof of file delivery across the state of Michigan, while still providing linear television / media services, provides a compelling rationale for automotive support by ATSC 3.0 broadcasters.

Previous work in Phoenix and Santa Barbara [4] proved the ATSC 3.0 physical layer is a viable option for broadcasters to support the automotive industry. Work has expanded to test reception across multiple markets with proper ATSC A/331 signaling pointing receivers to similar automotive service in other markets. Testing Service handoff in the receiver along with locating gaps in RF coverage provide practical examples of receiver behavior in transition regions between markets.

In this paper the ATSC 3.0 Standard description of how to accomplish file delivery across multiple frequencies is first explained, specifically the use of Multiple Frequency Networks (MFN) is described, followed by file delivery characterizations. Next, the field test transmitter setup is described with details including PHY configurations, followed by the tested driven route and receiver setup. Results of two separate field tests, including media service handoffs and NRT delivery of files, is presented. Extrapolation is made to larger file sizes, and the conclusion indicates the successes and some possible future work.

II. ATSC A/331 Standard

ATSC 3.0 A/331 Signaling, Delivery, Synchronization, and Error Protection standard [2] includes many signaling options. Signaling of Service starts with what A/331 describes as Low Level Signaling (LLS), which is a UDP stream of packets containing tables sent on a known destination address of 224.0.23.60 on port 4937.

The ATSC 3.0 protocol stack diagram from A/331 Section 5.1 is shown in Figure **II.1**. The LLS is the starting point for entry into the protocol stack. The LLS contains tables that convey a Service List Table (SLT), system time, or other messages. This starting point is indicated on the left side of the diagram with a yellow box where SLT is labeled. Although the ATSC 3.0 standard supports both MMTP and ROUTE transport protocols, this experiment tested the ROUTE protocol pictured in the middle of the diagram with a black box and red text because it supports delivering NRT files along with Dynamic Adaptive Streaming over HTTP (DASH) delivery of media.

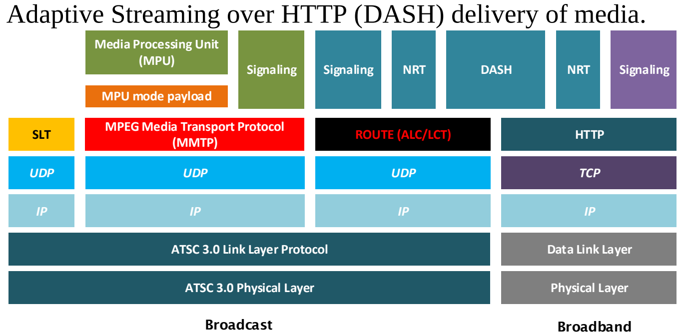

Figure II.1 ATSC 3.0 Protocol Stack

The Service List Table (SLT) (i.e., LLS_table_id = 1) contains the signaling required for MFN and is an XML-based document. The SLT has a few key elements and attributes to support MFN that are highlighted in green in Table II.1. Table II.1 is a subset of the SLT for brevity in this paper. The elements and attributes of interest for MFN are the `SLT.Service@serviceId` attribute, which must be the same across RF channels, `SLT.Service.OtherBsid` element pointing to the other broadcasters' signals and the `OtherBsid@type` attribute. The yellow-highlighted entries are proposed extensions to the SLT which were not available from vendor equipment at the time of the field test. These extensions are to aid receivers in choosing best possible options to gain or keep a service in transition regions.

Table II.1 Subset of Service List Table

Element or Attribute Name	Use	Data Type	Short Description
SLT			Root element of the SLT.
@bsid	1	slt:listOfUnsignedShort	Identifies the one or more Broadcast Streams comprising the Services.
SLTCapabilities	0..1	sa:CapabilitiesType	Required capabilities for decoding and meaningfully presenting the content for all the Services in this SLT instance.
SLTInetUrl	0..N	anyURI	Base URL to acquire ESG or SLS files available via broadband for all Services in this SLT.
@urlType	1	unsignedByte	Type of files available with this URL.
Service	1..N		Service information.
@serviceId	1	unsignedShort	Integer number that identifies this Service within the scope of this Broadcast area.
@globalServiceID	0..1	anyURI	A globally unique URI that identifies the ATSC 3.0 Service. This attribute is not present for the ESG, EAS, and DRM Data Services.
@sltSvcSeqNum	1	unsignedByte	Version of SLT Service info for this Service.
@protected	0..1	boolean	Indicates whether one or more Components needed for meaningful presentation of this Service are protected (e.g. encrypted).
...			
OtherBsid	0..N	slt:listOfUnsignedShort	Identifier(s) of other Broadcast Stream(s) that deliver duplicates or portions of this Service.
@type	1	unsignedByte	Indicates whether the Broadcast Stream identified by the **OtherBsid** delivers a duplicate or a portion of this Service.
Other Rf	0..N		Supplies details about the transmission location and strength of other broadcasts which are indicated in **SLT.Service.OtherBsid**
@OtherBsidRf	1	unsignedShort	Indicates the center channel RF frequency (in MHz) of the broadcast with the broadcast identifier of SLT.Service.OtherRf@OtherBsid.
@otherBsid	1	unsignedShort	Identifier of the Broadcast Stream broadcast on **OtherRf**. Linkage between SLT.Service.OtherBsid and SLT.Service.OtherRf is via the value of otherBsid.
@lat	1	float	Latitude of transmitter location (-90.0 ≤ lat ≤ 90.0)
@long	1	float	Longitude of transmitter location (-180.0 ≤ long ≤ 180.0)
@elev	1	integer	Antenna radiation center Height Above Mean Sea Level (nearest meter)
@erp	1	integer	Antenna Effective Radiated Power (ERP), in kW
Directional	0..N		Describes the directionality of the transmitter/antenna
@heading	1	nonNegativeInteger	Heading in degrees, 0 ≤ @heading < 360
@strength	1	float	The relative field value of the emission in the direction of @heading
@haat	0..1	integer	The Height Above Average Terrain in the @heading direction

A/331 [2] Section 5.8 and Section 5.8.1 explain Service delivery via multiple RF Channels without channel bonding. Section 5.8 explains the difference between 'portion' and 'duplicate' service. Specifically, "A set of Components of such a Service is called a "portion" of the Service when the set does not consist of all Components of the Service and more than one such set of Components make up the Service." This means if a Service is allowed to have local commercial breaks, 'portion' should be used to indicate that at least some of the programming could be different across markets. Other programs intended for stationary TV devices available on an LDM Enhanced PLP are allowed to be completely different. Furthermore, A/331 goes on to state that the **SLT.Service.OtherBsid** element is used to signal whether a Service is delivered in more than one RF channel. And the **OtherBsid@type** attribute is used to indicate the type of a set of Components of a Service, either "portion" or "duplicate."

Section 5.8.1 states, "Each ATSC 3.0 Service represented by either Service portions or duplicates shall be included in SLTs of the RF channels in which the portions or duplicates appear. Each of these multiple listings of a Service, referencing its portions or duplicates, shall have the same value of Service ID, and except for **OtherBsid@type** =3, the same value of major/minor channel number.

This consistency of values enables the multiple portions or duplicates of a Service carried in multiple RF channels to be consolidated into a single Service in the channel map[s] of receivers when they perform channel scans. The SLT entry for an essential portion or any duplicate of such a Service also shall have one or more **OtherBsid** element(s) indicating the BSID(s) of the Broadcast Stream(s) in which the other portion(s) or duplicate(s) can be found."

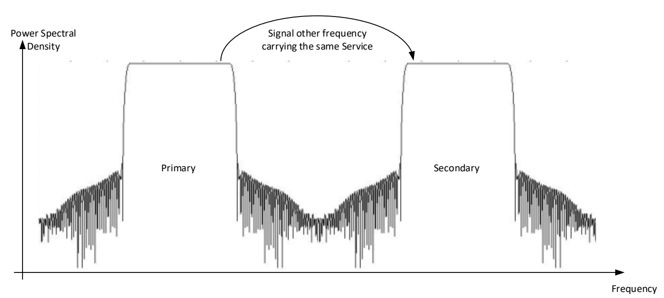

Figure II.2 MFN Signaling

As a receiver travels across markets, there could be many RF allocations available. Figure **II.2** may help visualize the process. The primary channel is tuned, and in the background, a secondary tuner scans all available RF allocations (TV channels

2 through 36) searching for a channel with a BSID matching one of those listed in the primary channel's **OtherBsid** element. Other broadcaster BSID values are listed in Table II.2. Once a secondary channel is found, a receiver then determines when there is high enough received signal strength on the secondary channel and low enough signal strength on the primary channel to switch over to the new frequency.

Table II.2 Broadcaster BSIDs

Broadcaster	BSID	OtherBsid@type
WMYD	1486	Portion
WKAR	1494	Portion
WOLP	9046	Portion
WXSP	5022	Portion

If media is being presented, the Secondary channel Service List is searched for the same **SLT.Service@serviceId** as the primary channel so that one program can be watched from one market to the next. For this field test, the NRT files were carried in the runtime environment. That environment is signaled with the HELD signaling located in the same **SLT.Service@serviceId** SLS. This allows watching the same program as well as receiving the same NRT files from one market to the next.

III. File Delivery

Delivering a file to multiple markets involves broadcasters working together and signaling each other's Services. This Multiple Frequency Network (MFN) is enabled by ATSC's A/331 standard [2] and is described in the next Section. A/331 enables file delivery in a few ways, particularly:

1: In a runtime environment,
2: In a dedicated ROUTE session that could be hidden
3: In a private channel (User Defined Service with LLS Table ID 0xFF).

Depending on the size of a file, each of those methods could be considered for alignment with specific business use-cases (e.g., large file delivery at night, or carouseling small pieces throughout the day, etc.). File delivery for private use should not impact media services of a broadcaster. Depending on file size or desired robustness of delivery, one of the options above should be chosen. For this field test, using the runtime environment allowed ease of integration, as most available equipment supports this runtime environment. Sony's ATSC 3.0 protocol stack software also supports this environment and is easily logged.

ATSC 3.0 specifies a ROUTE protocol that is FLUTE-based for file delivery of media and ordinary files. The only difference is media files are real-time DASH segments containing audio and video content. Non-real-time ordinary files can be delivered with the choices listed above, and this field test used the runtime environment.

A. Video Handoff

While coordinating efforts for ordinary file delivery across multiple RF allocations, handoff of media Service naturally falls into the test plan. Each broadcast media program has a Service ID that can be shared across other broadcasts. As vehicles travel from market to market, that Service ID can be searched by receivers and, if found, switched to when there is enough received energy to pick up that Service in the next market. Automatic handoff of Service was tested and successfully accomplished with a NASA program feed from their satellite. WKAR and WMYD both received the same NASA program, and handoff of service between Lansing and Detroit, Michigan was possible.

B. NRT File Delivery

To avoid receivers not participating in the field test downloading large files and possibly overflowing their memories, small files were used. This also allowed quick proof of reception and allowed easy identification of locations with packet loss. The chosen files were JPG pictures of 154 and 357 kilobytes. Larger files certainly can be delivered, but to avoid TVs downloading large files, a separate Service for automotive applications based on private use (User Defined LLS Table ID 0xFF) or an Application-based hidden Service (**SLT.Service**@serviceCategory = 3) should be used.

For this field test, along with the small NRT files, a small broadcaster APP was sent. This APP counted the number of correct full file receptions. The APP and two files were put into a carousel that serially delivered the files in the ATSC runtime environment. Sony's receiver (CXD2885 CLOVER chip with SHES-A protocol stack software running on an NVIDIA [1] Shield Android OS) received the APP, started it, and then the APP counted the number of files delivered.

IV. Transmitter Setup

There were four transmitters configured for the field test, WMYD in Detroit, WKAR in Lansing, WOLP and WXSP in Grand Rapids. A description of the PHY configurations for all four transmitters, with a few parameters from ATSC A/322 [1], is provided in Table **IV.1**.

Table IV.1 Transmission Parameters

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 AWGN C/N	-2.90 dB	20.88 dB

Each broadcaster has contracts to provide linear television services to stationary devices, so these services were not modified, and an automotive service with over 2Mbps payload was added using a Layered Division Multiplexing (LDM) configuration. The drawback in this configuration is that a

[1] NVIDIA trademark is the property of NVIDIA Corporation.

slightly higher SNR (around 1 dB more) was required for the stationary services.

Setting the LDM Core PLP to operate at almost -3dB SNR allowed extremely robust reception substantially outside the ATSC 1.0 coverage area. The payload was well protected with the PHY layer Forward Error Correction (FEC). Additional protection can be applied with Application Layer FEC (AL-FEC), which can have the added benefit of chunking up large files and putting repair bits on the backs of those chunks. A dedicated private Service or hidden APP-based Service is a better fit, however, for long dropouts of the sort that can occur between markets and is an area for future investigation.

V. Driving Routes and Signal Coverage

Longley-Rice and TIREM modeling tools were used to predict field signal strength in the three markets across Michigan, Detroit, Lansing and Grand Rapids. The Longley-Rice model was used with 1.5-meter antenna height to predict field strength and the results, combined with the planned drive route, is shown in Figure V.1.

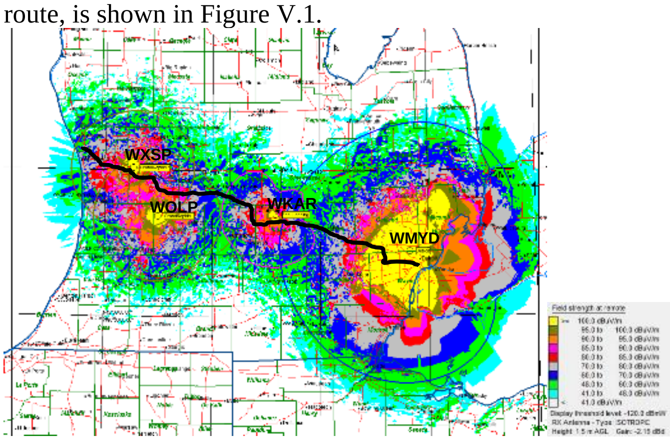

Figure V.1 Longley-Rice Field Strength Prediction

The Longley-Rice model is what the FCC uses to predict field strength of broadcast emissions and assign licenses, only using 10meter antenna height. TIREM modeling accounts for more terrain factors and can be more accurate. TIREM model results with the same 1.5meter antenna height and planned drive route are shown in Figure V.2.

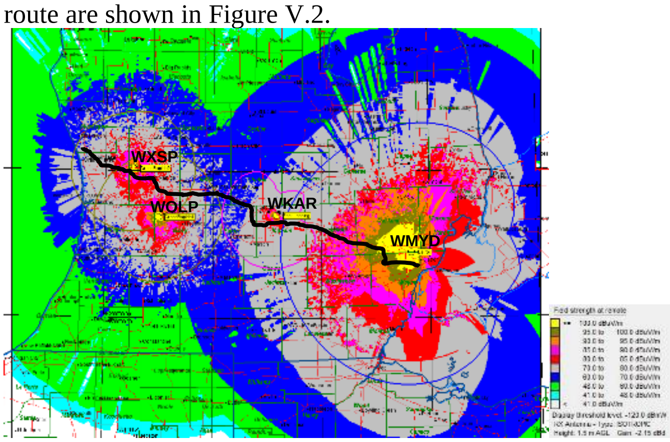

Figure V.2 TIREM Field Strength Prediction

For this field test, the I-96 interstate was used to go through all four transmitter coverage areas. The drive started in downtown Detroit and went all the way to Lake Michigan via I-96 and back. This field test was therefore nicknamed "Michigan Coast 2 Coast". This test entailed highway speeds and flat terrain as the purpose was to test NRT file delivery across multiple markets. Further details about testing signal strength and differing terrain types are available in [4].

WMYD operates at 935kWatts ERP on Channel 31 (575MHz). WKAR operates at 5.5kWatts ERP on Channel 35 (599MHz). WOLP operates at 14.4kWatts ERP on Channel 35 (599MHz) and WXSP operates at 15kWatt ERP on Channel 15 (479MHz).

These plots indicate service coverage could be possible in each market, but transition regions especially between Lansing and Grand Rapids can be challenging. The physical layer is configured with LDM and the automotive service is carried on the core PLP operating at –2.9dB SNR. Effectiveness of that robust QoS carrying into these transition regions will be shown in the results VII. Note, WKAR and WOLP operate on the same frequency of Channel 35 and are not in an SFN operation so some interference could occur between Lansing and Grand Rapids as well as low signal strength. WMYD of Detroit is very strong and should enable service handoff between Detroit and Lansing's WKAR.

VI. Receiver Setup

A. Hardware

Sony Semiconductor's CXD2885GG-W LSI (CLOVER) was mounted on a board designed by SHES-A (CRIMSON) and powered through USB-C connectors. Input RF signal is applied through four pairs of UHF and VHF antennas via SMA-style connectors which are then passed into the CX2885GG-W which contains four digital television tuners, four multi-region digital television demodulators, as well as an integrated CPU and USB 2.0 bridge functions. Both the CX2885GG-W, as well as the dongle's supporting hardware, were designed for automotive-grade environments. In these test cases presented, all four tuners and demodulators are enabled, utilizing 4-diversity Maximum Ratio Combining (MRC) technology. Demodulated output signals are formatted into ALP packets and then streamed over the USB 2.0 interface to an external host (NVIDIA Shield TV Pro in these tests). Provisions for increased USB VBUS supply current over USB Type-C were included into the board's hardware design allowing the dongle to be completely powered from a single USB Type-C host device as shown in Figure **VI.2**.

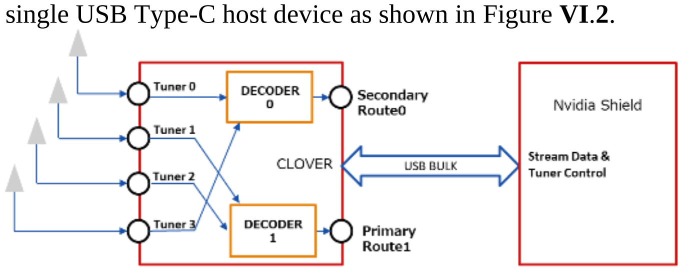

Figure VI.1 CXD2885GG Configuration

CLOVER configuration had 2 demodulator paths, these are named the primary and secondary paths and are as shown in Figure VI.1. The primary Route 1 was set to use Tuners 1 and 2 and the secondary Route 0 was set to use Tuner 0 and 3. Both paths use the USB BULK transfer to the NVIDIA Shield. Once data is sent to the Shield, SHES-A's Android APP picks up and processes the data. The locations of these antennas are indicated in Figure VI.4.

B. Software

Sony's SHES-A group developed a Proof of concept (PoC) ATSC 3.0 protocol stack software that was used to assess the capability of an ATSC3 receiver to accurately download non real time data over standard ATSC3 A/331 [2] ROUTE protocol. This PoC software is JAVA code designed to run on an Android based OS. NVIDIA Shield products have that Android OS and Android 9.0 (Pie) version of that NVIDIA Shield provided fast processing speed for this ATSC 3.0 protocol stack processing.

The PoC does not currently employ any AL-FEC or other techniques to correct or mitigate file downloads so that assessment of future needs of such correction could be done. The technologies that might be useful for correction and the algorithms that might be useful to achieve the best results are the subject future work.

In this regard, expected data loss would allow for an understanding of the sources of the elements that caused the losses. In the first test run of Michigan Coast to Coast looking at handoff of media Service, the PoC focused on Audio/Video (AV) delivery and handoff in a multi-frequency environment. AV playback can be tolerant of bit losses and thus video monitoring is not so indicative of what is required for complete file delivery needed for NRT. The PoC still includes the capability of automated seamless handoff across MFN market transitions which was a goal of the first test run that proved successful between Lansing and Detroit.

In the 2nd test run, focus was placed on assessing continuous throughput of NRT files. This test required the broadcasting of two JPEG pictures of around 157kByte and 365kByte interspersed with a small APP in a carousel. The HELD signaling of an appContextId as stated in A/331 [2] was respected and required by the PoC for reception of the pictures using further standard A/344 [3] signaling.

In a typical ATSC3.0 runtime environment, a receiver would download a file once, based on TOI uniqueness, and subsequently ignore any further instances until expiry or removal. In this NRT download test the PoC was modified to allow any instance of the pictures to be downloaded. The reason for this modification was to assess what future parameters are need for a very large file to be downloaded, where chunking or error correction could allow for success, without multiple revisits to a file carousel. If a very large file takes 3 hours to download, revisiting the carousel 5 times to get this file would not be good practice. Demonstrating that the same pictures (NRT files) could be received across multiple markets was key. A goal was to achieve automated seamless handoff for these multicast file deliveries.

C. Field Test configuration

A test vehicle was prepared with the wiring diagram shown in Figure **VI.2**. The Crimson board was developed by Sony HES-A team as a USB dongle that could interface with an Android based device. The received signal was split between Sony Semiconductors CLOVER evaluation Kit and this USB based dongle so that registers could be read inside the CLOVER chip as well as monitor media services at the same time. A camera was also used to record operation of the receivers.

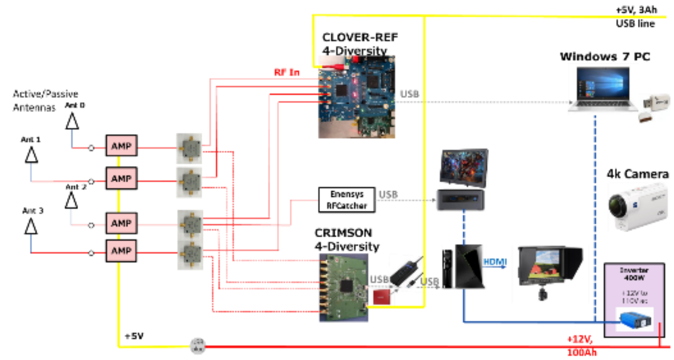

Figure VI.2 Field test wiring diagram

Antennas used for this field test only needed to support the UHF band as all transmitters were between channels 15 and 36. Chaowei DVB66 High VHF / UHF antennas as listed in Table **VI.1** proved to work well, if there was a metal roof to serve as a ground plane. The test vehicle of a Nissan Kick provided enough ground plane for good sensitivity. Amplifiers also came from Chaowei providing an extra 25dB gain.

Table VI.1 Field test antennas

Tuner 0: Chaowei DVB66, ~2dB Gain	**Blue** color PLOTS
Tuner 1: Chaowei DVB66, ~2dB Gain	**Orange** color PLOTS
Tuner 2: Chaowei DVB66, ~2dB Gain	**Gray** color PLOTS
Tuner 3: Chaowei DVB66, ~2dB Gain	**Yellow** color PLOTS

Proper calibration of the receiver is needed to report accurate received signal strength indication (RSSI) at the antenna. A block diagram shows the main components from the antenna to the demodulator in Figure VI.3. Register readings from the Sony Semiconductor demodulator were calibrated by subtracting the total loss of 14.632 dB from all reported results.

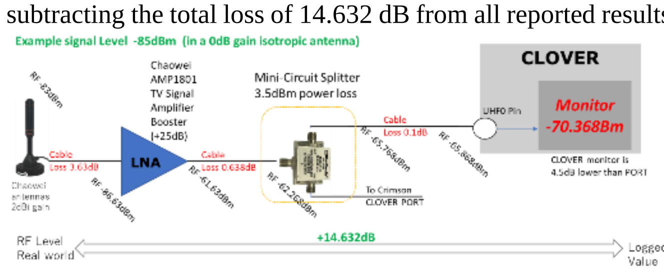

Figure VI.3 Receiver tuner in put block diagram

The four antennas were placed at the corners of the vehicle roof as shown in Figure VI.4.

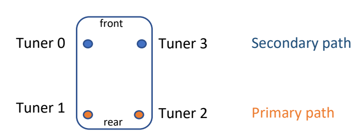

Figure VI.4 Antenna placement on vehicle

VII. Results

Two test runs were conducted. The first run tested automotive media Service handoff, RF gaps, and coverage area with LDM PHY configuration. The second run tested NRT file delivery in the runtime environment with the high Quality of Service (QoS) PLP (core layer PLP) across multiple markets.

A. *Service Handoff*

Received signaling starts with the Service List Table. That is listed below, where the automotive Service (ID = 5007) is highlighted.


```
<SLT xmlns="tag:atsc.org,2016:XMLSchemas/ATSC3/Delivery/SLT/1.0/" bsid="1486">
  <Service serviceId="3" sltSvcSeqNum="0" serviceCategory="1"
globalServiceID="https://doi.org/10.5239/1BF0-983C" majorChannelNo="7" minorChannelNo="1"
shortServiceName="WXYZ">
    <BroadcastSvcSignaling slsProtocol="1" slsDestinationIpAddress="239.255.7.1"
slsDestinationUdpPort="8000" slsSourceIpAddress="204.78.46.16"/>
  </Service>
  <Service serviceId="4" sltSvcSeqNum="0" serviceCategory="1"
globalServiceID="https://doi.org/10.5239/04FF-D9E9" majorChannelNo="4" minorChannelNo="1"
shortServiceName="WDIV">
    <BroadcastSvcSignaling slsProtocol="1" slsDestinationIpAddress="239.255.4.1"
slsDestinationUdpPort="8000" slsSourceIpAddress="204.78.46.16"/>
  </Service>
  <Service serviceId="5" sltSvcSeqNum="0" serviceCategory="1"
globalServiceID="https://doi.org/10.5239/F96A-3F22" majorChannelNo="2" minorChannelNo="1"
shortServiceName="WJBK">
    <BroadcastSvcSignaling slsProtocol="1" slsDestinationIpAddress="239.255.2.1"
slsDestinationUdpPort="8000" slsSourceIpAddress="204.78.46.16"/>
  </Service>
  <Service serviceId="6" sltSvcSeqNum="0" serviceCategory="1"
globalServiceID="https://doi.org/10.5239/B911-767A" majorChannelNo="62" minorChannelNo="1"
shortServiceName="WWJ">
    <BroadcastSvcSignaling slsProtocol="1" slsDestinationIpAddress="239.255.62.1"
slsDestinationUdpPort="8000" slsSourceIpAddress="204.78.46.16"/>
  </Service>
  <Service serviceId="5007" sltSvcSeqNum="0" serviceCategory="1"
globalServiceID="https://doi.org/10.5239/5C6F-EB73" majorChannelNo="20" minorChannelNo="99"
shortServiceName="WMYD-MO">
    <OtherBsid type="2">1494</OtherBsid>
    <OtherBsid type="2">9046</OtherBsid>
    <OtherBsid type="2">5022</OtherBsid>
    <BroadcastSvcSignaling slsProtocol="1" slsDestinationIpAddress="239.255.20.99"
slsDestinationUdpPort="8000" slsSourceIpAddress="204.78.46.16"/>
  </Service>
  <Service serviceId="1" sltSvcSeqNum="0" serviceCategory="1"
globalServiceID="https://doi.org/10.5239/D67B-BE30" majorChannelNo="20" minorChannelNo="1"
shortServiceName="WMYD-HD">
    <BroadcastSvcSignaling slsProtocol="1" slsDestinationIpAddress="239.255.20.1"
slsDestinationUdpPort="8000" slsSourceIpAddress="204.78.46.16"/>
  </Service>
  <Service serviceId="65024" sltSvcSeqNum="0" serviceCategory="4" shortServiceName="SG-FE00">
    <BroadcastSvcSignaling slsProtocol="1" slsDestinationIpAddress="239.255.0.255"
slsDestinationUdpPort="8000" slsSourceIpAddress="204.78.46.16"/>
  </Service>
</SLT>
```


The **`SLT.Service.OtherBsid`** element values are listed there for Lansing and Grand Rapids transmitters. The **`SLT.Service@serviceId`** attribute value of 5007 is tuned in, demodulated and decoded according to the Service Layer Signaling (SLS) which consists of an MPD, USBD, and S-TSID. The S-TSID lists IP addresses of all available services and the received S-TSID is provided below where the ROUTE Session of interest is highlighted (239.255.20.99:8000). This Route Session will change in different markets, but the **`SLT.Service@serviceId`** of 5007 will not, and the receiver will pick up the new ROUTE session once tuned, demodulated and decoded.

The second highlighted ROUTE session is dedicated to NRT files and indicates the broadcaster application and 2 files being sent. This does not have to be a dedicated ROUTE session, those NRT files could be sent in the same ROUTE session as the video, but in separate LCT channels (TSI's).


```
<S-TSID xmlns="tag:atsc.org,2016:XMLSchemas/ATSC3/Delivery/S-TSID/1.0/"
xmlns:afdt="tag:atsc.org,2016:XMLSchemas/ATSC3/Delivery/ATSC-FDT/1.0/"
xmlns:fdt="urn:ietf:params:xml:ns:fdt">
  <RS dIpAddr="239.255.20.99" dPort="8000">
    <LS tsi="10" startTime="1970-01-01T00:00:00Z">
      <SrcFlow rt="true">
        <EFDT>
          <FDT-Instance Expires="4294967295" afdt:efdtVersion="6" afdt:maxTransportSize="262761"
afdt:fileTemplate="video-$TOI$.mp4a">
            <fdt:File Content-Location="video-init.mp4v" TOI="4294967295"/>
          </FDT-Instance>
        </EFDT>
        <ContentInfo>
          <MediaInfo repId="Video1_1" contentType="video">
            <ContentRating value="1,'TV-14',{0 'TV-14'}"/>
          </MediaInfo>
        </ContentInfo>
        <Payload codePoint="128" formatId="1" frag="0" order="true"/>
      </SrcFlow>
    </LS>
    <LS tsi="20" startTime="1970-01-01T00:00:00Z">
      <SrcFlow rt="true">
        <EFDT>
          <FDT-Instance Expires="4294967295" afdt:efdtVersion="6" afdt:maxTransportSize="36036"
afdt:fileTemplate="audio-0-$TOI$.mp4a">
            <fdt:File Content-Location="audio-0-init.mp4a" TOI="4294967295"/>
          </FDT-Instance>
        </EFDT>
        <ContentInfo>
          <MediaInfo repId="Audio2_2" contentType="audio"/>
        </ContentInfo>
        <Payload codePoint="128" formatId="1" frag="0" order="true"/>
      </SrcFlow>
    </LS>
    <LS tsi="30" startTime="1970-01-01T00:00:00Z">
      <SrcFlow rt="true">
        <EFDT>
          <FDT-Instance Expires="4294967295" afdt:efdtVersion="6" afdt:maxTransportSize="18768"
afdt:fileTemplate="d3_3-$TOI$.m4s">
            <fdt:File Content-Location="d3_3-init.mp4" TOI="4294967295"/>
          </FDT-Instance>
        </EFDT>
        <ContentInfo>
          <MediaInfo repId="d3_3" contentType="subtitles"/>
        </ContentInfo>
        <Payload codePoint="128" formatId="1" frag="0" order="true"/>
      </SrcFlow>
    </LS>
  </RS>
  <RS dIpAddr="239.255.20.100" dPort="8000">
    <LS tsi="16">
      <SrcFlow>
        <EFDT>
          <FDT-Instance Expires="4294967295">
            <fdt:File Content-Location="File Carousel.multipart" TOI="1" Content-Length="1899"
Content-Type="multipart/related" afdt:appContextIdList="carousel"/>
          </FDT-Instance>
        </EFDT>
        <Payload codePoint="128" formatId="3" frag="0" order="false"/>
      </SrcFlow>
    </LS>
    <LS tsi="17">
      <SrcFlow>
        <EFDT>
          <FDT-Instance Expires="4294967295">
            <fdt:File Content-Location="ATSC_3.0_towers.jpg" TOI="2" Content-Length="157452"
Content-Type="multipart/related" afdt:appContextIdList="carousel"/>
          </FDT-Instance>
        </EFDT>
        <Payload codePoint="128" formatId="3" frag="0" order="false"/>
      </SrcFlow>
    </LS>
    <LS tsi="18">
      <SrcFlow>
        <EFDT>
          <FDT-Instance Expires="4294967295">
            <fdt:File Content-Location="Auto-Show_Riverfront-skyline.jpg" TOI="3" Content-
Length="365468" Content-Type="multipart/related" afdt:appContextIdList="carousel"/>
          </FDT-Instance>
        </EFDT>
        <Payload codePoint="128" formatId="3" frag="0" order="false"/>
      </SrcFlow>
    </LS>
  </RS>
</S-TSID>
```


Incoming Audio/Video files were shown with Transport Object Identifier (TOI) values incrementing because the **`SrcFlow.Payload@formatId`** attribute of the LCT channel in this ROUTE session was set to FILE MODE. The continuous incrementing of files being opened indicates continuous playback of video. The demodulator lock status for the trip from Lake Michigan to Detroit is shown in Figure VII.1.

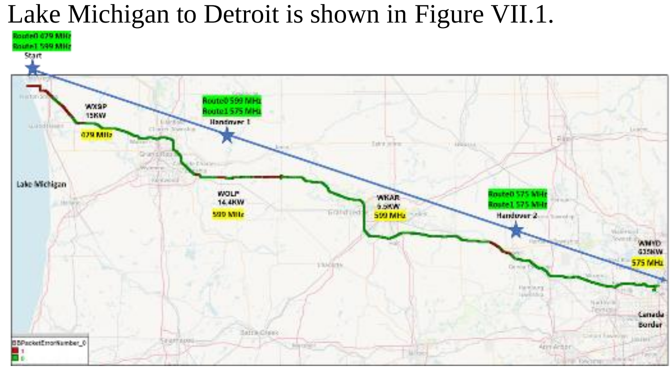

Figure VII.1 Lake Michigan to Canada Core PLP Baseband Packet reception

Starting out at Lake Michigan, Channel 15 (479 MHz) reception was not available at the coast likely due to very low signal strength. Upon review of the Received Signal Strength Indication (RSSI) logs, it was determined that the noise floor was higher than expected, likely due to weak ground planes

Files of type AV at tsi 10			
FileName	Length KB	Rcvd Ago ms	Opened Ago ms
/video-init.mp4v	0	233	
/video-1639935038.mp4a	107	222	51
/video-1639935037.mp4a	83	1,219	1046
/video-1639935036.mp4a	99	2,233	2039
/video-1639935035.mp4a	113	3,241	3088
/video-1639935034.mp4a	65	4,223	4050
/video-1639935033.mp4a	107	5,253	5076
/video-1639935032.mp4a	76	6,220	6060
/video-1639935031.mp4a	60	7,192	7003
/video-1639935030.mp4a	122	8,227	8026
/video-1639935029.mp4a	90	9,231	9040
/video-1639935028.mp4a	67	10,212	10022
/video-1639935027.mp4a	103	11,229	11047
/video-1639935026.mp4a	80	12,222	12040

Files of type AV at tsi 20			
FileName	Length KB	Rcvd Ago ms	Opened Ago ms
/audio-0-init.mp4a	0	220	
/audio-0-1639935056.mp4a	12	166,972	166766
/audio-0-1639935038.mp4a	12	152	
/audio-0-1639935037.mp4a	12	1,171	965
/audio-0-1639935036.mp4a	12	2,162	1980
/audio-0-1639935035.mp4a	12	3,172	2962
/audio-0-1639935034.mp4a	12	4,142	3994
/audio-0-1639935033.mp4a	12	5,161	4989
/audio-0-1639935032.mp4a	12	6,161	5942
/audio-0-1639935031.mp4a	12	7,153	6936
/audio-0-1639935030.mp4a	12	8,162	7954
/audio-0-1639935029.mp4a	12	9,171	8946
/audio-0-1639935028.mp4a	12	10,161	9948
/audio-0-1639935027.mp4a	12	11,142	10949
/audio-0-1639935026.mp4a	12	12,151	11960

Files of type AV at tsi 30			
FileName	Length KB	Rcvd Ago ms	Opened Ago ms
/d3_3-init.mp4	0	553	
/d3_3-1639935056.m4s	0	167,002	
/d3_3-1639935038.m4s	0	182	
/d3_3-1639935037.m4s	0	1,183	
/d3_3-1639935036.m4s	0	2,183	
/d3_3-1639935035.m4s	0	3,193	
/d3_3-1639935034.m4s	0	4,173	
/d3_3-1639935033.m4s	0	5,203	
/d3_3-1639935032.m4s	0	6,182	
/d3_3-1639935031.m4s	0	7,162	
/d3_3-1639935030.m4s	0	8,181	
/d3_3-1639935029.m4s	0	9,181	
/d3_3-1639935028.m4s	0	10,181	
/d3_3-1639935027.m4s	0	11,181	
/d3_3-1639935026.m4s	0	12,182	

Figure VII.2 File Logs

which the omni antennas required. Reception started at Nunica, around the I-96 Exit 10 for highway 104 to Grand Haven. From there Channel 15 was received until just east of Gerald R Ford Airport. This confirms WXSP has full coverage of Grand Rapids. Once east of the airport, Channel 15 SNR dipped below the reception threshold and sufficient SNR was seen in Channel 35 (599 MHz) so the switch to the new frequency was made.

Channel 35 is WOLP and WKAR, hence reception of channel 35 just east of Grand Rapid airport is likely WOLP for a short while until WKAR in Lansing is reached. WOLP's Channel 35 energy is hard to see in these graphs, the SNR never really peaked above 10dB. Received signal strength was in and out for some time, but then WKAR's energy became strong and program source was switched. This is shown in Figure VII.3 directly on the right.

The 2nd handoff to channel 31 occurred east of Lansing. The color schemes are the same as previously with primary path in blue and secondary path in green. When the secondary path saw enough SNR and the primary path lost enough SNR, a handover was made.

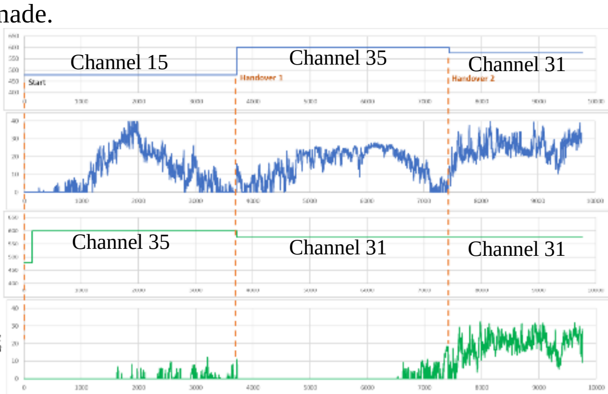

Figure VII.3 Lake Michigan to Canada handover points

Figure VII.2 (full page width) shows logs from Sony's Android APP that indicate Audio-Video (AV) files being received and opened continuously across 3 LCT channels (Transport Session Identifier 'TSI' values 10 for video, 20 for 1st audio track, 30 for closed captions). Note, closed captions were not enabled so those files are not being opened. The source of these segments is from the primary CLOVER path, route 1.

The listing of all these segments can be seen to increment one by one, indicating ALL audio-video files are being received and opened for video processing. No files are lost or packets dropped when strong signal energy was received. Video recording of the media playback also confirms continuous media playback. When the vehicle was within a market, solid reception was available. The transition regions between markets have some dropouts as shown with red no ALP Lock points in Figure VII.1.

B. *NRT File Delivery in Runtime Environment*

Instead of using handoff's, separate CLOVER route paths were selected to extract NRT files out of PLP0, the automotive QoS PLP with high robustness. The environment is relatively flat terrain with small rolling hills. There are some tall trees but no tall buildings. Therefore, it was expected that the channels could be received if SNR was higher than 0dB.

In each CLOVER route path both the core PLP and enhanced layer PLP were recorded, but only the core PLP ALP lock results are plotted at each recorded GPS position as that PLP has the high robustness intended for automotive service. Recordings were taken every 0.5 seconds. Core PLP ALP lock results are shown in Figure VII.4. The drive started at Lake Michigan and went to Detroit, so first reception was with WXSP, Channel 15.

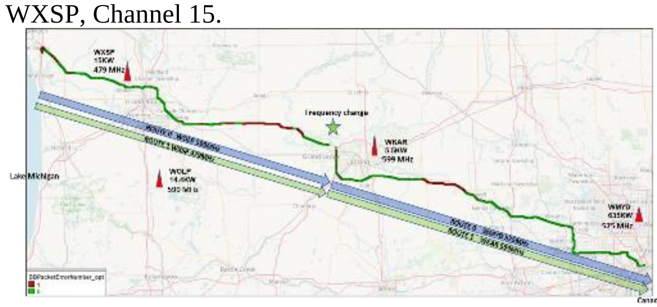

Figure VII.4 Core PLP ALP lock results

The frequency was changed halfway through the drive to pick up the expected signals in the coming markets. Secondary route 0 path was updated to look for channel 31 and primary route 1 path was updated to look for channel 35. At this change point, the GPS appears to have dropped out a bit, likely due to the USB cable coming undone for a short period of time.

Using the same protocol stack decoding for video, the SLS also has a HELD entry. That HELD is shown below.

```
<HELD xmlns="tag:atsc.org,2016:XMLSchemas/ATSC3/AppSignaling/HELD/1.0/">
<HTMLEntryPackage appContextId="carousel" bcastEntryPackageUrl="File Carousel.multipart" bcastEntryPageUrl="clock3.html"/>
</HELD>
```

This signaling informs the receiver to start an HTML5 based runtime environment where HTML5 applications can run. It points to the package containing the APP starting with an AppContextId of 'carousel' matching the same name for appContextIdList="carousel" in the S-TSID that informs the receiver to look at ROUTE session 239.255.20.100:8000 and in LCT channel TSI = 16. In that LCT channel, a package named "File Carousel.multipart" is located and should be unpacked and run with the entry page "clock3.html".

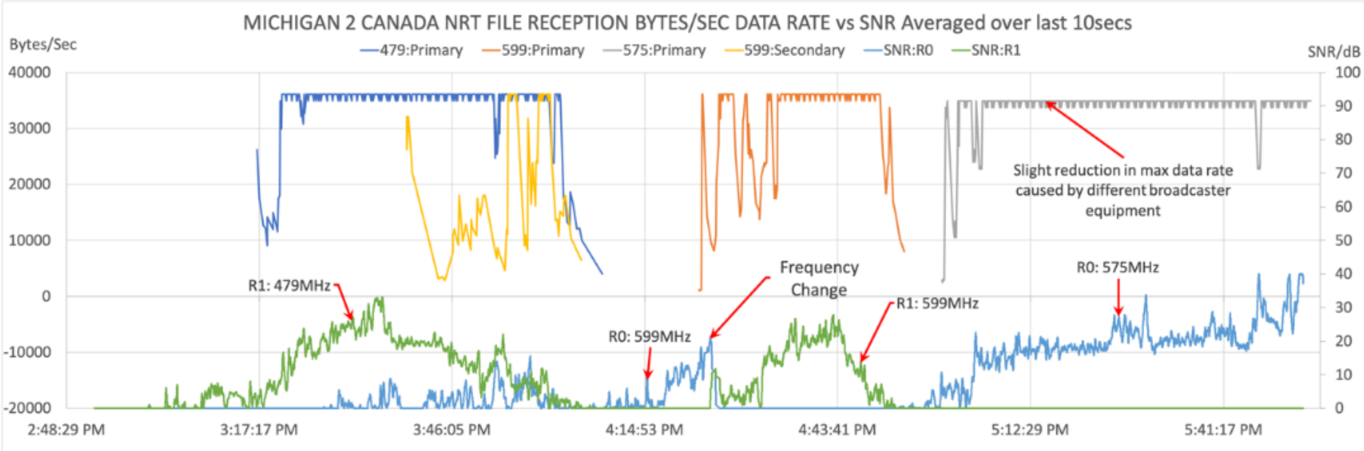

Figure VII.5 NRT file reception vs SNR

That APP started counting the number of times two other files, one in LCT channel 17 and one in LCT channel 18 under the same ROUTE session 239.255.20.100:8000 was correctly received. With the files being relatively small size, byte rates were plotted for correct reception as the vehicle travels the interstate at highway speeds. The small file size quickly indicates problem areas. A plot of those results is provided in Figure VII.5.

The graph shows data rates of the NRT files in Bytes /sec with the left axis and the right vertical axis indicates average SNR for each CLOVER route path as time incremented through roughly 3 hours. The light blue plot at the bottom shows CLOVER route 0 (secondary) path average SNR and the green plot at the bottom shows CLOVER route path 1 (primary) path average SNR.

The SNR plots are from the Sony Semiconductor evaluation kit with some 10 second averaging (length of transmission of largest picture). They show when the frequency for the different Route paths is being switched as we transition the markets. The data rate information is from the PoC receiver software where the primary antennas are is always connected to route1 in its Clover board and the secondary antennas are connected to route0.

The following Figure VII.6 gives more insight as to the cause of the drops in data rate by observing the number of packet errors (PEN). No averaging was applied to the PEN. The data for this figure was modified to include a small negative PEN offset for the routes to indicate the unlock condition such that the source for a zero PEN could allow for distinguishing between unlocked with no data and locked with good data. The graph indicates that for most of the drive lock was available with just short spells of unlock in the transition areas.

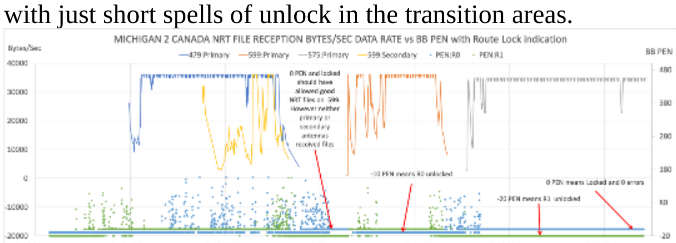

Figure VII.6 NRT file reception vs Packet Errors

First it should be noted that the discontinuities between markets are clearly visible. Second, when inside a market, the NRT file reception rate is very high. There are a few glitches (or dips in the received byte rate) of the two files. Those glitches could likely be solved with an application layer FEC (AL-FEC) that ATSC 3.0 [2] specifies as RAPTOR-Q. Third, when video reception was good, correct reception of NRT files was confirmed. Finally, when the SNR was above 0dB, at least some files were received, as the operating point of the physical layer is approximately -2.9dB SNR. There was one anomaly just before WKAR reception where the secondary path has enough SNR, but when switched to the primary path, the SNR dropped below 10dB and file reception became challenging for a bit. The primary path used antennas at the back of the vehicle and perhaps this was a factor in getting poor reception in the west side of Lansing.

WOLP file reception was available, but not at a consistent rate as with WXSP, WKAR and WMYD. Signal strength was a bit lower than WXSP but they both operate around 15kWatt ERP. The reason for lower SNR from WOLP could warrant further study.

The bouncing data rates around 35kBytes/sec are File 1 and File 2 being correctly received with 154kBytes and 357kBytes respectively in a ~300kByte (2.6Mbps) size PLP. When video was good, correct reception of NRT files was confirmed. When there were video artifacts, then the reception of NRT files would immediately suffer, proving that small file size quickly indicates packet loss.

Received Signal Strength Indication (RSSI) was also recorded during the drive and is shown in Figure VII.7. The numbers are calibrated with the equipment setup as shown in Figure VI.3. Low average SNR from WOLP can be correlated to low received signal strength. However why that signal strength is lower than expected is an unanswered question.

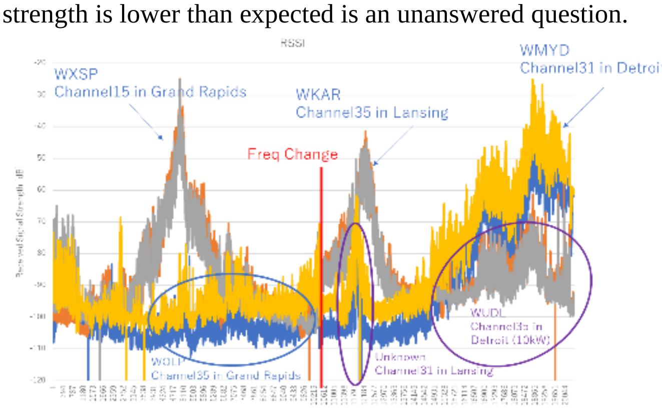

Figure VII.7 RSSI

Figure VII.7 shows that the secondary path picked up another channel 31 in Lansing. Also, it is interesting that the primary path picked up channel 35 in Detroit, possibly WUDL. In either case, those channels are not using ATSC 3.0 modulation and were not decoded and therefore did not interfere with testing.

C. Larger File Size

While testing small file sizes enables each tracking of packet loss locations, it is not a likely scenario for business use-case. Larger file sizes can be delivered via ATSC 3.0 with consideration of other devices in the market.

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 speed of delivery entirely depends on how much bandwidth is allocated and at what Quality of Service (SNR operating point) is chosen for this automotive application-based service. An example is the bandwidth used for file delivery in the runtime environment which has bandwidth for the core PLP of 2.6Mbps (325kBytes). The files delivered were 154kByte, 357kByte in size and the APP was 1kBytes, all carousel in series. Total use of the core PLP is 512KB which means roughly every 2 seconds, the files would carousel.

For any file multicast delivery, there are 2 points to consider

1. Speed of delivery
2. Quality of Service

These are related in that the speed of delivery is controlled with bandwidth allocation and the QoS is set by the operating point (Signal to Noise Ratio). For a 1 GB file, running at the same -2.9 dB SNR operating point providing 325 kB payload, it would take

$$Time = \frac{File\ Size}{Bandwidth} = \frac{1000000000\ [bytes]}{325000\ [\frac{bytes}{sec}]} = 3077\ [sec]$$

…or approximately 51 minutes.

At -2.9 dB SNR, that would provide a high degree of confidence the file would reach all vehicles in a market, those in garages, parking structures, etc. but the tradeoff is the time to deliver that file and hence battery life considerations of the vehicle. However, for example if a larger bandwidth of 15.23 Mbps payload running at 11 dB SNR operating point, the time would be much less at

$$Time = \frac{File\ Size}{Bandwidth} = \frac{1000000000\ [bytes]}{1903750\ [\frac{bytes}{sec}]} = 526\ [sec]$$

…or approximately 9 minutes.

At 11 dB SNR, that would provide reasonable confidence the file would reach most vehicles in the market, but maybe not ones on the fringes of the coverage area or deep inside garages. However, delivering a 1 GB file in less than 10 minutes would save battery life.

In addition to these factors, consider the number of times a file could carousel. 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. Considerations of all these tradeoffs might be offered by broadcasters for customers to decide; let the customer decide the level of quality files are multicast to a market.

VIII. Conclusion

ATSC 3.0 can provide multi-frequency networks in different markets, and with a robust PHY layer file delivery is proven to work in the runtime environment in each market. This field test proves when a vehicle is within a market, the ATSC 3.0 receiver will very likely receive those files. But if the vehicle travels outside the market, or is in a transition to the next market, then a 2nd radio option would be needed to ensure file reception in market transition locations.

It is a business discussion whether market transition areas are to be covered by an MFN. Having an automotive application that interfaces with other radios to mitigate issues of transition could offer larger coverage areas for automotive customers.

High correlation can be seen the results where if SNR > 5dB then full file reception occurs in all locations within a market. Sony Semiconductor's CXD2885GG chip has shown to provide robust ATSC A/322 reception along with strong software algorithms in SHES-A ATSC 3.0 protocol stack solution. Options of automatic handoffs of service and caching of file delivery even when starting in the middle of a file have proven useful.

ATSC 3.0 multicasting files is a viable option for broadcasters to support the automotive industry. Whether that is with infotainment, fleet management, software updates, autonomous driving support of maps, traffic, or whatever, ATSC 3.0 offers compelling reasons to use broadcasting for vehicular communications.

Acknowledgment

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References

[1] ATSC: "ATSC 3.0 Physical Layer Protocol," Doc. A/322:2021, Advanced Television Systems Committee, Washington, D.C., 20 January 2021.

[2] ATSC: "ATSC Signaling, Delivery, Synchronization, and Error Protection," Doc. ATSC A/331:2022, Advanced Television Systems Committee, Washington, D.C., 16 February 2022

[3] ATSC: "ATSC Interactive Content," Doc. ATSC A/344:2021, Advanced Television Systems Committee, Washington, D.C., 23 March 2021

[4] ATSC 3.0 Automotive Field Tests, https://www.sony.com/content/dam/sony/landing-pages/whitepaper-atsc30_automotive_field_tests_.pdf

Luke Fay is a Senior Manager Technical Standards for Sony Home Entertainment & Sound Products - America. Currently he is involved with the development of the next generation of

broadcast television in a variety of standards organizations and their efforts to educate members of the new possibilities available with ATSC 3.0. He has over 20 years of experience in digital communications systems engineering and receiver design.

He received a BS in Electrical Engineering from University of Arizona and an MS degree in Electrical Engineering from National Technological University. He has been granted over 13 patents in the area of Digital Signal Processing. He is currently serving as Chairman of the Advanced Television Systems Committee (ATSC) Technology Group 3 (TG3). He is also the recipient of the 2015 Bernard J Lechner Award for technical and leadership contributions to the ATSC. He became a SMPTE Fellow in 2018.

Graham Clift is a Principal Hardware Engineer for Sony Home Entertainment & Sound Products - America.