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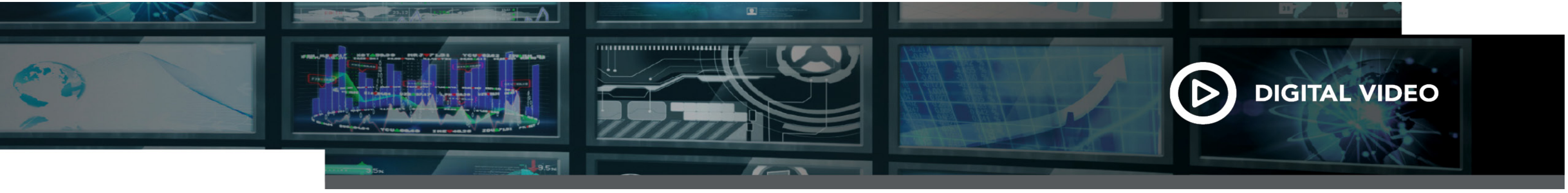

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Society of Cable Telecommunications Engineers
International Society of Broadband Experts

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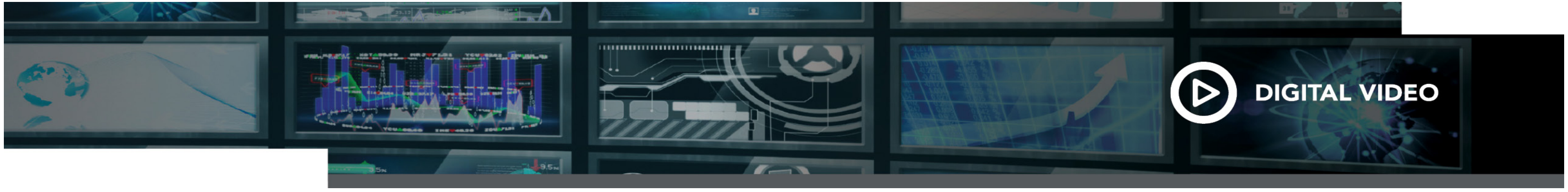

Table of Contents

4 **From the Editor**

5 **All Coming Together: A Collaborative Effort To Achieve Comprehensive End-To-End Ad Monitoring**
Mourad Kioumgi, VOD Solutions Architect, Sky UK, Sky Group, Comcast
Chris Hock, Head of Business Strategy and Development, Media & Entertainment, Adobe
Dan Murray, Director, Product Marketing, Video Solutions, Contributor, Telestream
Xavier Denis, Director, IP Ad Insertion Products, Contributor, CommScope

24 **Taming Video Spectrum Management For Distributed Access Architecture (R-PHY And R-MACPHY)**
Christopher Poli, P.E., Sr. Director Product Management, CommScope

43 **Driving Adoption of IP Edge Devices**
Steven Riedl, SER Consulting LLC
Joel Derrico, Principal Engineer, Cox Communications
David Brown, Verimatrix
Steve Reynolds, President, Imagine Communications
Chris Gordon

61 **Blockchain-as-a-Service Application in Digital TV**
Srilal Weerasinghe PhD, Principal Engineer, Charter Communications

74 **Diagnosing Visual Quality Impairments in High-Dynamic-Range/Wide-Color-Gamut Videos**
Zhou Wang, Professor, University of Waterloo
Hojatollah Yeganeh, Senior Member Technical Staff, SSIMWAVE Inc.
Kai Zeng, Senior Member Technical Staff, SSIMWAVE Inc.
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Welcome to the December issue of the *Journal of Digital Video*, a publication of collected papers by the Society of Cable Telecommunications Engineers (SCTE) and its global arm, the International Society of Broadband Experts (ISBE). This edition of the journal focuses on various aspects of the digital video sector.

It is well acknowledged that advertising is one of the revenue engines that contributes heavily to cable and online distribution. Dynamic ad campaign management and targeting have also contributed to revenue but also system complexity increases. The first article gives an overview of methods for effective verification of these complex systems – advertisers often insist on verification before payment is given. This paper describes several methods that are usable in different large-scale implementations.

As video distribution continues to be a significant use of plant bandwidth, innovative new technologies permit increases in effective bandwidth without massive infrastructure rebuilds . The second paper describes techniques used to increase bandwidth available for data services.

Content distribution from program provider to distributor has been one of the *least-changed* technologies from the early days of cable to the current time. However, recent developments in FCC spectrum reassignment and the ubiquity of IP capacity are moving the *least-changed* technology to the *most-quickly disrupted*. The third paper describes novel applications of new methods of content distribution from programmer to consumption points.

The fourth paper describes how Blockchain technology can be used in interactive content and other services to ensure privacy, synchronization and, verification of consumer input. Secure and private two-way interaction between end-consumers and the service provider has been a challenge and can benefit from the cryptographic principles of Blockchain.

SCTE•ISBE standards, and the operators that adopt them, keep high-quality content and services as top-of-mind goals. In the final paper, the newest high-quality video, High Dynamic Range (HDR) / Wide Color Gamut (WCG) is explored from the qualitative perspective. HDR/ WCG sets consumer expectations of picture quality to a new level. This paper explores the impairments that may impact HDR / WCG video.

We thank the individuals who contributed to this issue of the *Journal of Digital Video*, including the authors, peer reviewers, and the SCTE•ISBE publications and marketing staff. We hope you enjoy this issue and that the selected papers spark innovative ideas and further cement essential knowledge in digital video.

In closing, if there is any editorial information or topics that you would like us to consider for the next issue of *SCTE•ISBE Journal of Digital Video*, please refer to the "editorial correspondence" and "submissions" sections at the bottom of the table of contents for instructions.

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All Coming Together: A Collaborative Effort To Achieve Comprehensive End-To-End Ad Monitoring

A Streaming Video Alliance Members Endeavor

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Table of Contents

Title **Page Number**

Table of Contents ______ 6
1. Introduction ______ 7
2. Problem Statement ______ 7
3. Typical Use Cases of Faults ______ 8
4. The Proof of Concept – Demonstrations Based on User Cases ______ 11
5. Manifests with AD-IDs ______ 11
    5.1. Components Used – Dynamic Ad Insertion (Ad Manifest Manipulators) ______ 11
    5.2. Components Used – ABR Video Probes ______ 12
    5.3. Components Used – Source Probes ______ 15
    5.4. Components Used – Visual Quality Probes ______ 15
    5.5. Components Used – Player ______ 15
    5.6. Components Used – ABR Monitoring ______ 16
    5.7. Components Used – Visualization Board ______ 18
6. POC Results ______ 21
7. Conclusion ______ 21
    7.1. What's Needed for the Future ______ 21
8. Abbreviations ______ 22
9. About the Streaming Video Alliance ______ 23
10. Notice 23

List of Figures

Title **Page Number**

Figure 1 - High Level Architecture 11

Figure 2 - The IQ Video Management System (IVMS) 13

Figure 3 - The IQ Video Management System (IVMS) Monitoring Performance 14

Figure 4 - The IQ Video Management System (IVMS) Telestream Monitoring Points 14

Figure 5 - Open Source Player with Nice People At Work QoE Analytics 16

Figure 6 - OTT ABR Status Dashboard 17

Figure 7 - Live Status Detail 18

Figure 8 - VirtualNOC End-To-End Overview 19

Figure 9 - VirtualNOC End-To-End Delivery Workflow – Error Detection 20

Figure 10 - VirtualNOC End-To-End Delivery Workflow – History 21

1. Introduction

With Ad-Supported Video-on-Demand (AVOD) business models gaining widespread adoption and advertising on live now an intrinsic part of the streaming experience, we are witnessing huge demand from the advertiser community.

Delivering ads within streaming video involves multiple systems all working together, from defining campaigns, to stitching the ad into the video to delivering it to the client to verifying the ad was watched, and more. Yet, while some components can provide good visibility and analytics into large sections of the ad delivery workflow, there are gaps in providing an end-to-end solution for monitoring, troubleshooting and providing analytics that cover the system as a whole.

For example, video analytics solutions are linked to video players and report on key playback events like content starts, quartiles, title, duration, ad start/end, player specific quality of service (QoS), etc. Other important metrics, such as which ads were served, the associated campaigns and which segments were targeted may be available in the ad server (ADS). And Manifest Manipulation systems can act as the glue of the system, passing important campaign, client and targeting data between components, which gives them good visibility into the execution of ads and the performance of the system as a whole.

However, there is an opportunity to improve communication and consistency of how information is tracked and reported, allowing better visibility into the reasons for the failure of an ad to play, and providing insight into the factors that make an advertising deployment successful. And greatly increase the value of OTT technology for advertisers.

The Streaming Video Alliance Advertising Working Group has created and discussed a proposal/blueprint and associated test setup to demonstrate how to take advantage of this opportunity and address some of the Advertising challenges facing OTT providers today.

This paper will outline the collaborative integration of manifest delivery, analytics, quality metrics, visual dashboard and reporting methods while highlighting several demonstration use cases. This proof-of-concept study will prove helpful for Ad operations teams to enable a reliable Quality of Service across streaming devices while validating advertiser’s investments.

2. Problem Statement

Traditionally, video analytics solutions are linked to video players and report on key playback events like content starts, quartiles, title, duration, ad start/end, player specific QoS, etc. This information has several valuable uses:

- Marketers use it to understand and influence audience viewing behaviors
- Video operations teams use it to analyze and optimize playback quality and network behavior
- Ad operations teams use it to evaluate and optimize ad performance

However, the value to ad operations teams is limited with just this level of information. Ad ops teams also need to understand other important metrics--like which ads were played, the associated campaigns, and where the fault occurred in the ad serving chain --in order to make better use of their analytics solution.

This information is normally only available in the ad server, which is separate from the rest of the analytics / monitoring solutions. Combining traditional analytics and monitoring solutions and ad campaign reporting into a single system will greatly increase the value for advertisers.

This Streaming Video Alliance working group project will work on a proposal/blueprint and test setup to demonstrate how to overcome this challenge. Starting with the most complex which is server-side Ad insertion for Live streaming video.

3. Typical Use Cases of Faults

Common SSAI serving user cases

- Duration of ads inconsistent with ad creative
- Ad SCTE marker fails to reach downstream systems
- Malformed SCTE markers
- Malformed VAST/VMAP responses
- Ad creative is of poor visual quality or has distorted audio such as audio-level mismatch
- Ad creative chunks and manifest are not available / poorly hosted
- Ad campaigns are not fulfilled despite being scheduled by Ad manager
- Ad splicing components fail to create personalized manifests
- Misaligned Ad resolutions with main content
- Ad Manifest decoration is incorrect and missing key information

Use Case Descriptions

User case	Description	Impacts to ad serving
Duration of ads inconsistent with creative	The technical metadata provided by the Ad manager on the ad duration does not match the duration of the ad video asset. Note: other issues may occur with incorrect tech metadata, such as incorrect URLs.	Black frames on user's screen. Shortened ads being displayed.
Ad SCTE marker fails to reach downstream systems	The ad placement boundaries may fail to be inserted in the live streaming chain.	If no ad boundaries are signaled, then no ad replacement would occur. Resulting in lost revenue for the ad publishers and reduces fulfilment opportunities.
Malformed SCTE markers	The Ad placement SCTE marker may be incomplete/malformed. Could be missing key meta data inside its payload.	A failed ad insertion, can create a malformed ad call or 404 URL Missing binary information can lead to ad decisioning failing as its missing key info for downstream systems to react.
Erroneous VAST responses	The Ad Server may return ads in the VAST format, but the response may be malformed or have other issues. This may be more prevalent in programmatic ads when a demand system has not been properly integrated with the DAI system.	May cause error or failure in ad playback, sometimes resulting in the viewer seeing the underlying content or a slate instead of the ad.
Ad creative is of poor visual quality and has distorted audio	The ad creative was incorrectly encoded or is of a poor source quality when included in an ad campaign.	Blurry video or malformed audio disrupting the viewing experience of for the end user.
Ad creative chunks and manifest are not available, poorly hosted	The ad creatives may be hosted on a low performance video origin or may be missing video Chunks reference inside a manifest, or the manifest itself is not published as referenced inside the Ad manager.	Poor QoE experience on ad playback, due to missing chunks on origin Failed ad playback due to 404 on video manifest Slow origin resulting in Timeouts on video or buffering
Ad campaigns are not fulfilled despite being scheduled by ad manager	Ads schedules / campaigns are issued but the Ad manager isn't getting the impression data to confirm plays.	Loss of revenue and reduced confidence level in ad buyers and publishers.

User case	Description	Impacts to ad serving
Ad splicing components fail to create personalized manifests	The SSIA component which creates the personalized manifest for the end device users experiences a failure.	No video stream, loss of service Loss of revenue Impact to QoE and QoS of live streams
Misaligned ad resolutions with main content	Inserted ads do not have the same resolution or bitrates as the main video which they are inserted into.	ABR switch errors resulting in Buffering and impact to QoE Wrong bit rates resulting in spikes of bandwidth Correct bitrates are missing resulting in 404s on device because the bitrate does not exist
Ad manifest decoration is incorrect and missing Key information	Key metadata which may exist in the source video is excluded or is malformed inside the final manifest.	Reporting could fail because of missing data Other metadata that powers other playback features are missing and causes feature errors Ad breaks are malformed are wrong resulting in playback errors

4. The Proof of Concept – Demonstrations Based on User Cases

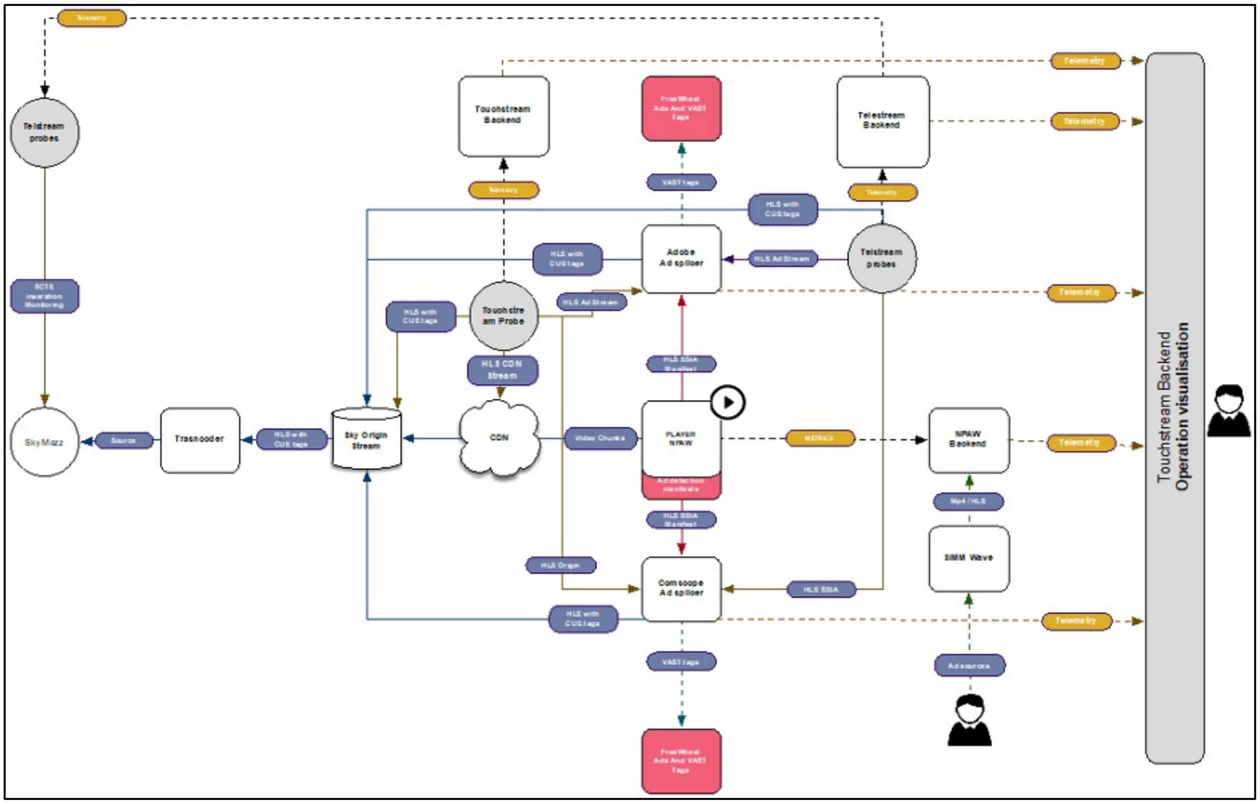

Figure 1 - High Level Architecture

5. Manifests with AD-IDs

How do we identify a fault with an ad across all the systems?

We did some extra work and extracted the “Ad-id” from the source (Ad manager) and populated this information across the whole chain. Now all tools and systems have viability and can triage efficiently across teams/components.

5.1. Components Used – Dynamic Ad Insertion (Ad Manifest Manipulators)

For this proof of concept, two different Dynamic Ad Insertion (DAI) systems were used to stitch targeted ads into the streams: (we used 2 systems in order to prove it was interoperable)

- Adobe Primetime Ad Insertion
- CommScope Manifest Delivery Controller (MDC)

The function of the DAI system is to orchestrate the insertion of ads—oftentimes, ads that are targeted to a particular viewer or household—into a VOD or live/linear stream. It does this by processing a properly conditioned stream or asset, whose manifest contains signals for the ad opportunities. Responding to signals in the stream/asset, triggering ad requests to the appropriate ad servers. Fetching the ad manifests and then stitching them tightly in the right spot in lieu of the stream manifest segments or period marked for replacement.

By allowing configurable metadata to be passed to clients through the manifests for HLS and DASH ad periods, the DAI system can typically help downstream probes identify ad break opportunities, pass tracking attributes like the ad-id, and trace the completion of each specific ad placements. Additionally, DAI systems such as CommScope MDC and Adobe Primetime Ad Insertion can support different verification flows, allowing clients to directly report trackers and impressions to the ad server, or sending the beacons on behalf of the client.

In cases of errors or problems, the DAI systems in this proof of concept provided great insights for quick troubleshooting, firstly by providing their outputs to the adaptive bit rate (ABR) video probes to monitor the ad insertion. Both systems output stitched manifests that were utilized by Touchstream's monitoring to look for ad tags, indicative of ad insertion or misses.

In addition, each DAI system had other ways for the ABR video probes to gather information as well. In this POC, CommScope exposed their APIs to Touchstream to enable stats to be aggregated to demonstrate how a missed opportunity (unreachable ad server, error from the ad server, lack of fill or underfill in the campaign) such as the returned "503 status" code can be reported by the DAI system. Also demonstrated was how an advertisement that cannot be found generates a "404 error". The ad-id tag is not present in the output manifest. CommScope MDC mitigates this situation by skipping to the next ad decision and continuing the insertion and stream delivery. Adobe turned debug mode on to enable the DAI system to send additional telemetry data to the probes in real-time in conjunction with the manifest responses. In addition to network information and error codes, this also includes timing information so turnaround time in fetching the audio and video assets for the content and ads can be ascertained and bottlenecks identified.

In addition to monitoring this information through the Touchstream page, each DAI vendor also has their own telemetry dashboard and tools to quickly and effectively troubleshoot DAI-related and/or system-level issues.

5.2. Components Used – ABR Video Probes

Telestream provided OTT stream operational monitoring at the Origin and CDN edge using Surveyor ABR, part of the IQ Quality Assurance family. Monitoring included manifest, video and audio quality assurance monitoring across all bitrate variants to verify good operation, identify issues, and use automation that assists operations to resolve issues quickly.

Surveyor ABR monitored the manifest, Ad-Insertion information, as well as video/audio at the Origin, and then again at the CDN edge. Monitoring at both Origin and CDN edge provides analytics related to manifest manipulator, ad server including ad video quality, as well as potential changes in video assets and performance at the CDN edge cache.

The IQ Video Management System (IVMS) collected monitoring data from the ABR monitoring probes to perform Ad-Insert data correlation between Source, Origin and CDN locations to enable operations to identify end-to-end performance and issue identification. The IQ video management system also includes Ad Insert business analytics such as expected vs actual avail times, avail minutes per hour, and ad-id

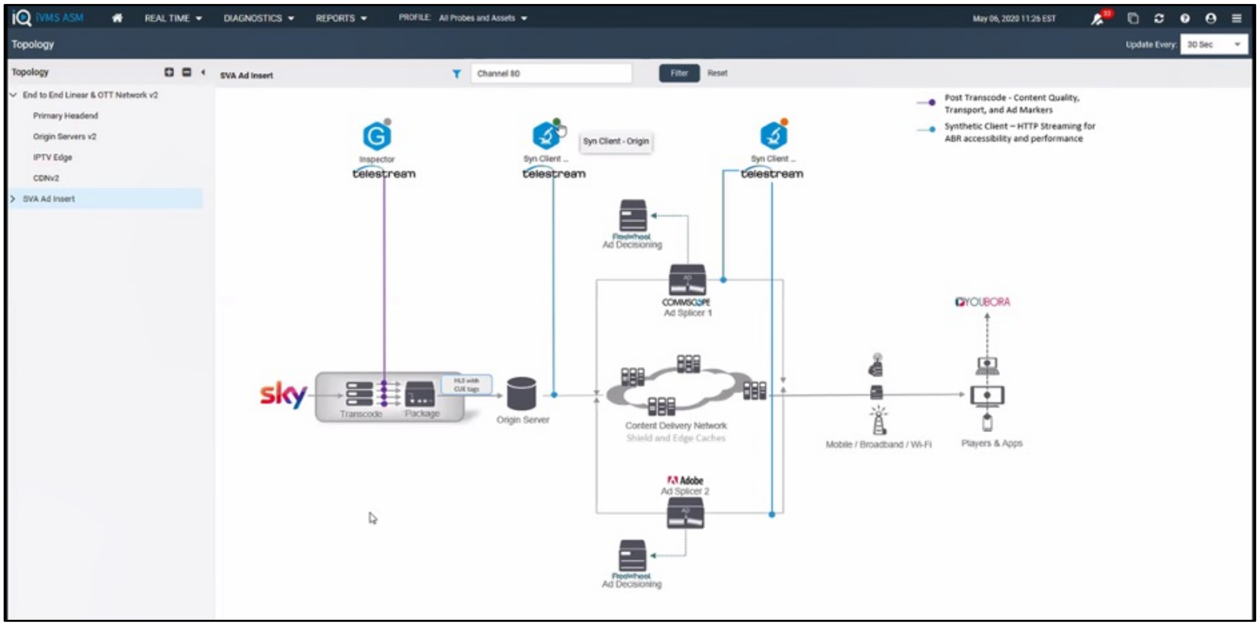

Figure 2 - The IQ Video Management System (IVMS)

Monitoring performance and ad insertion data across the network, and across all bit-rates variants can help operators pinpoint issues that Players may not find, because Players are designed to “adapt” to variants or CDN streams that work. The IQ management system provides the option to retain thumbnails for ads for confirmation and diagnostics.

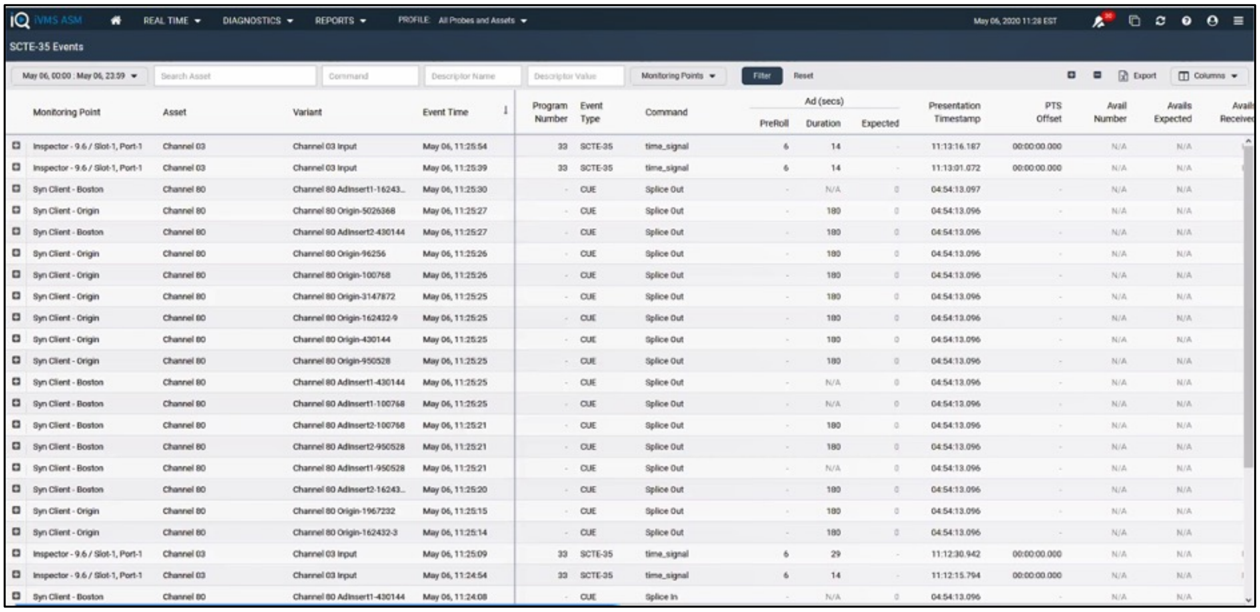

Figure 3 - The IQ Video Management System (IVMS) Monitoring Performance

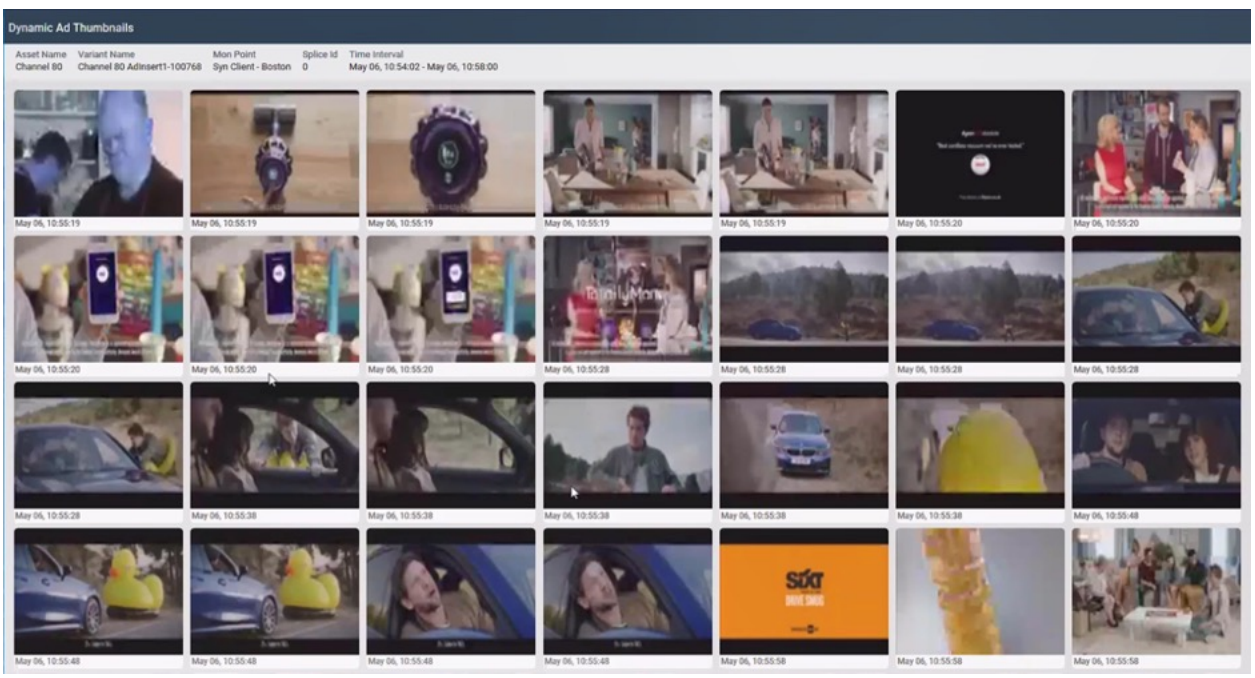

Figure 4 - The IQ Video Management System (IVMS) Telestream Monitoring Points

The northbound API on the IQ Video Management System was enabled for display of Telestream monitoring points on the demo dashboard provided by Touchstream.

5.3. Components Used – Source Probes

Telestream provided source monitoring for the linear encoder transport streams using Inspector Live software, part of the IQ Solutions family. The Inspector Live monitors the transport stream, video and audio quality, and the SCTE 35 ad insertion markers.

Inspector Live source monitoring and SCTE 35 data was provided to the same IQ Video Management System (IVMS) as used for ABR Origin and CDN monitoring, to provide a complete view of the ad insert SCTE 35 source to the Original and post DAI manipulated CDN edge. This provides operators a single pane-of-glass view of transport, video and ad-insert quality and correlation across the OTT delivery network. IVMS also supports Video Player correlation with NPAW Youbora and Conviva analytics, although not demonstrated by Telestream during this POC.

The same northbound API on the IQ Video Management System can be used to collect statistics of the Source, Origin and CDN edge to simplify third party displays including correlation and business intelligence data. Telestream provided API access to the Touchstream dashboard for the ABR monitoring points. The Source monitoring data can be provided on the same API for future demos.

5.4. Components Used – Visual Quality Probes

Telestream provided IQ monitoring probes in the POC that included video, audio and compliance quality analysis information. Multiple IQ monitoring probes also offer pixel-based MOS visual quality scoring as an option, however Telestream decided to focus on the ad-insert part of the POC and decided not to include pixel-based MOS scoring.

5.5. Components Used – Player

In order to gather client-side performance on ads an open source HTML5 player was used to consume the Ad conditioned streams provided by the SSAI ad components. inside the player Nice People at Work (NPAW) included their QoE analytics monitoring tool in order to capture key quality metrics on the ad placements. It important to have data captured on the client consuming the stream itself as that is where the real experience of the ads will be demonstrated, including errors and issues.

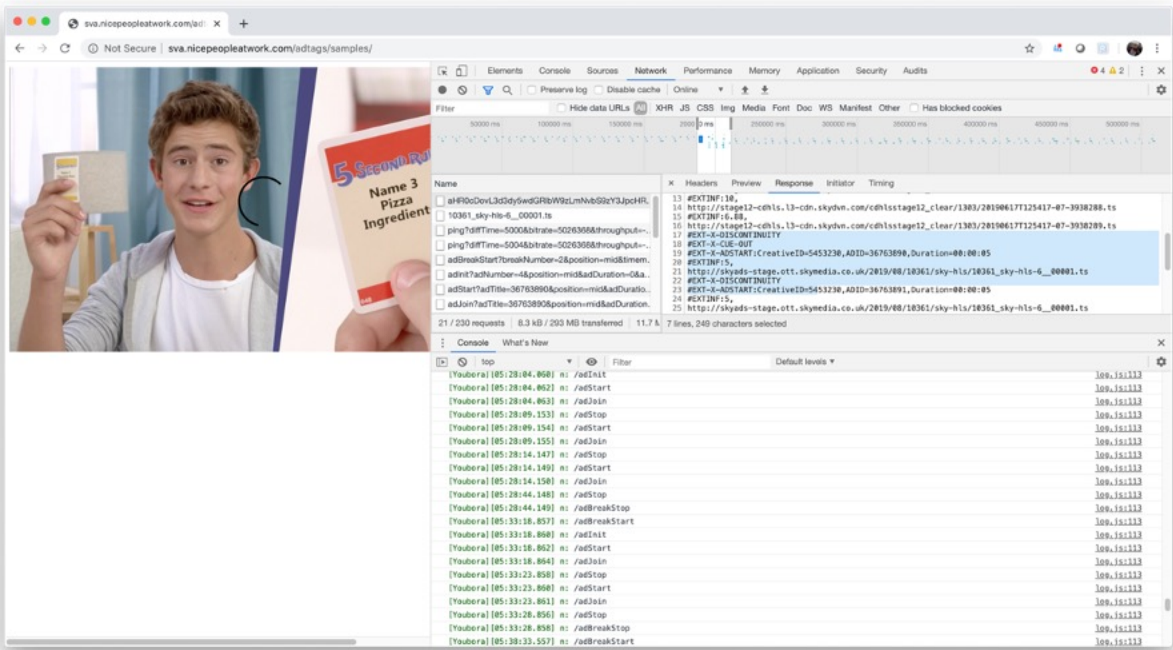

Figure 5 - Open Source Player with Nice People At Work QoE Analytics

The player itself would inspect the video manifest and then start recording the performance of the Ad opportunities by inspecting the timestamps for the “EXT-X-CUE” markers. Therefore, reporting on the ads themselves and not the main content. The ad QoE data was then sent back to a backend component (Yoboura) with the Creative id embedded in the manifest so that a data visualization tool could then extract individual ad performance on a given ad.

5.6. Components Used – ABR Monitoring

For this proof of concept, two different ABR Monitoring systems were used to monitor the streams at the Origin and the CDN, (we used 2 solutions in order to show it was interoperable):

- Telestream
- Touchstream

Touchstream provided access to the VirtualNOC's OTT ABR status monitoring and dashboards. The OTT ABR status dashboards are focused on the synthetic and independent monitoring of the CDN and origin endpoints for availability and performance by polling the stream endpoints from the Points of Presence (POPs) located at strategic locations across the Internet. Touchstream is a fully cloud-based solution that monitors the manifest and all bitrates every minute, capturing very detailed CDN and ad stitcher specific debug headers.

The endpoints monitored in this POC were:

- Origin

- CDN (raw, no ads)
- CommScope (ad stitched)
- Adobe (ad stitched)

Ad detection was enabled so that manifests with Ads playing were indicated:

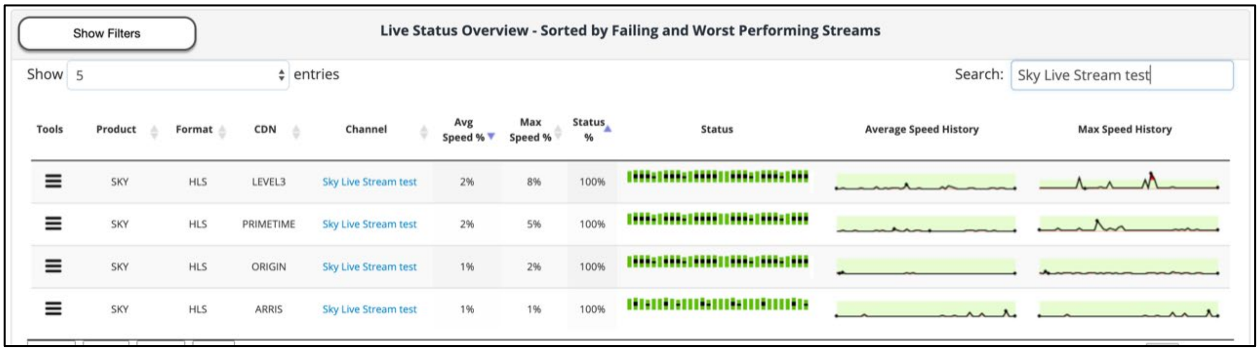

Figure 6 - OTT ABR Status Dashboard

At the top-level dashboard, the status sparkline each green block represents a one minute poll.

The large black dot in the middle represents that Touchstream has detected an ad is playing at the head of the stream. The slightly smaller black dot (always at the end of a series) is where an ad “CUE-OUT/CUE-IN” is detected in the manifest, but it is not at the head of the stream, i.e. the ad was playing at some point in the last minute.

Touchstream also enabled advance debug headers in the Adobe ad-stitched streams.

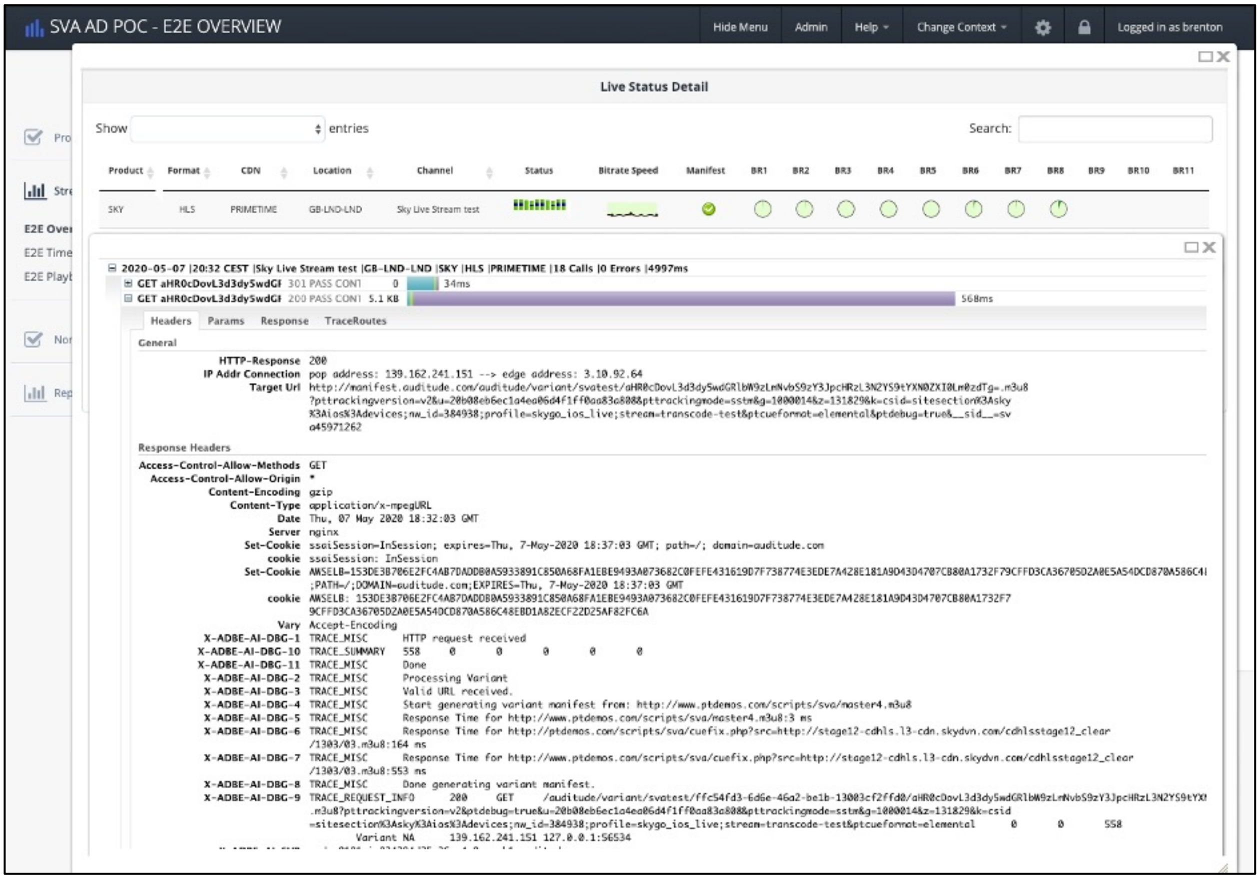

Figure 7 - Live Status Detail

These Adobe debug trace headers allow very deep investigation of the ad-stitching process.

5.7. Components Used – Visualization Board

Touchstream's VirtualNOC End-to-End visualization creates an overview of the entire video delivery chain. To build such an overview, Touchstream has a library of integrations for external vendors from ingesting, encoding, packaging, visual perception, ad insertion, audience player analytics, and many more.

The main purpose behind this visualization is to give operations teams a single high-level view of the workflow based on the most important KPIs from multiple disparate sources along the delivery workflow. VirtualNOC plays an important role as the single hub for all data as well as a context sensitive launch pad to dig deeper into problems by launching other vendor and internal tools and dashboards directly from the VirtualNOC dashboard.

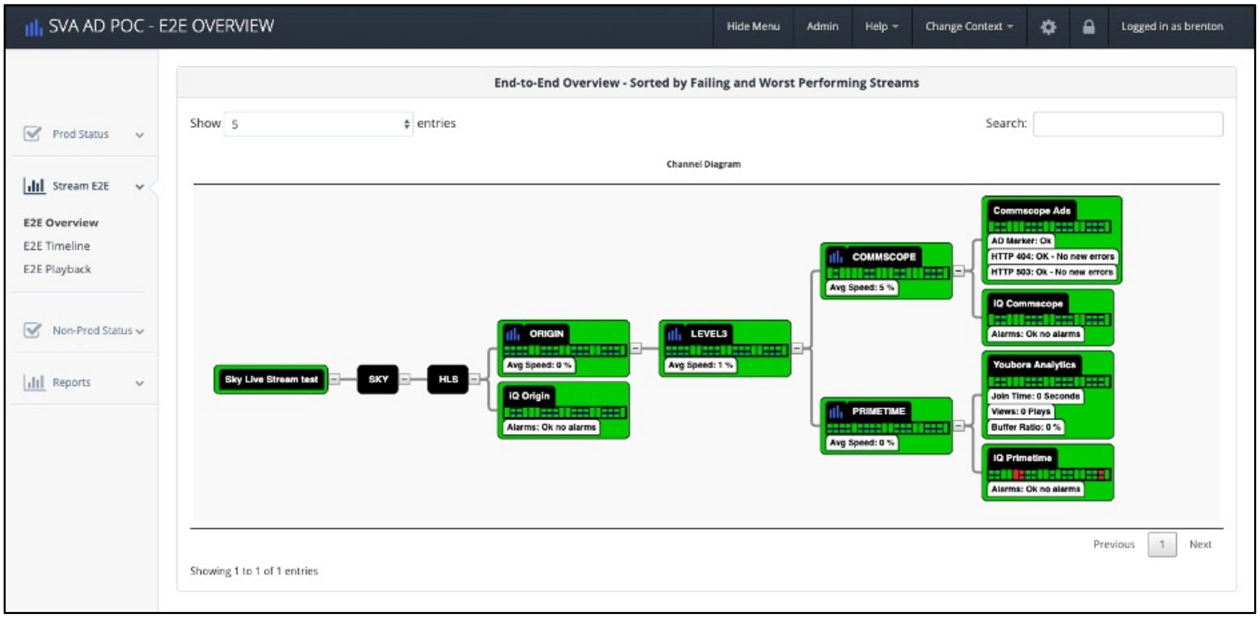

Figure 8 - VirtualNOC End-To-End Overview

For this POC Touchstream integrated external data from:

- Telestream
    - Raw source status
    - Origin status
    - CDN status
- CommScope
    - Add stitching KPIs
- NPAW Youbora
    - Audience Metrics

All data from Touchstream ABR monitoring and from all external data sources was integrated into a single End-to-End view.

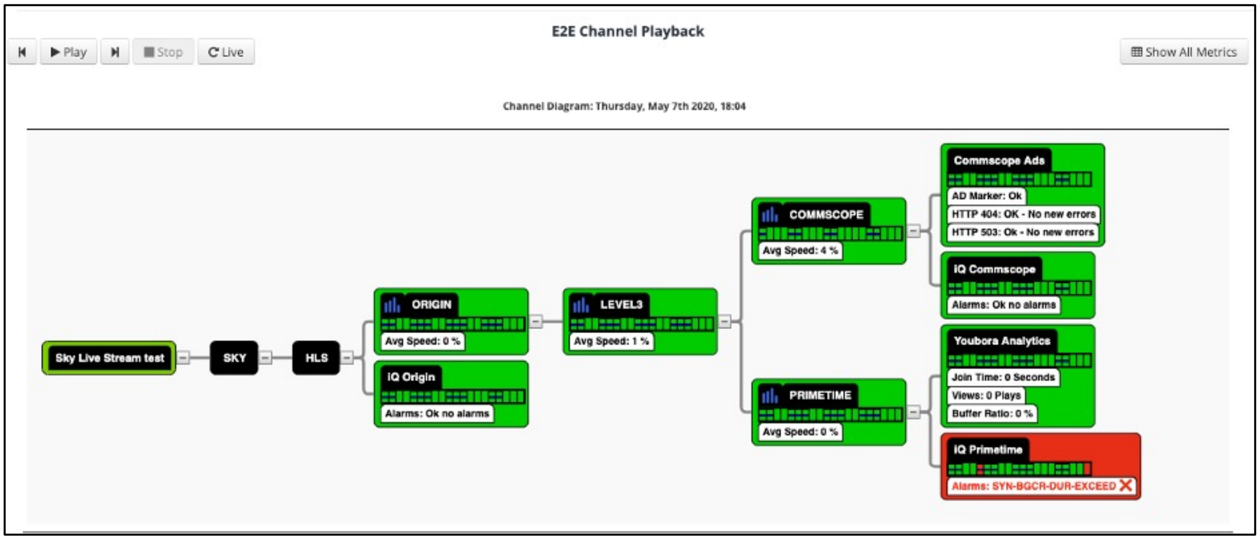

Figure 9 - VirtualNOC End-To-End Delivery Workflow – Error Detection

When any errors are detected from any part of the end-to-end delivery workflow, they are clearly indicated. In the above example an error via the Telestream iQ probe integration “SYN-BGCR-DUR-EXCEED” Alarm has been detected. From the Touchstream VirtualNOC dashboard, right click functionality is available to launch a Telestream iQ web interface to further investigate the problem.

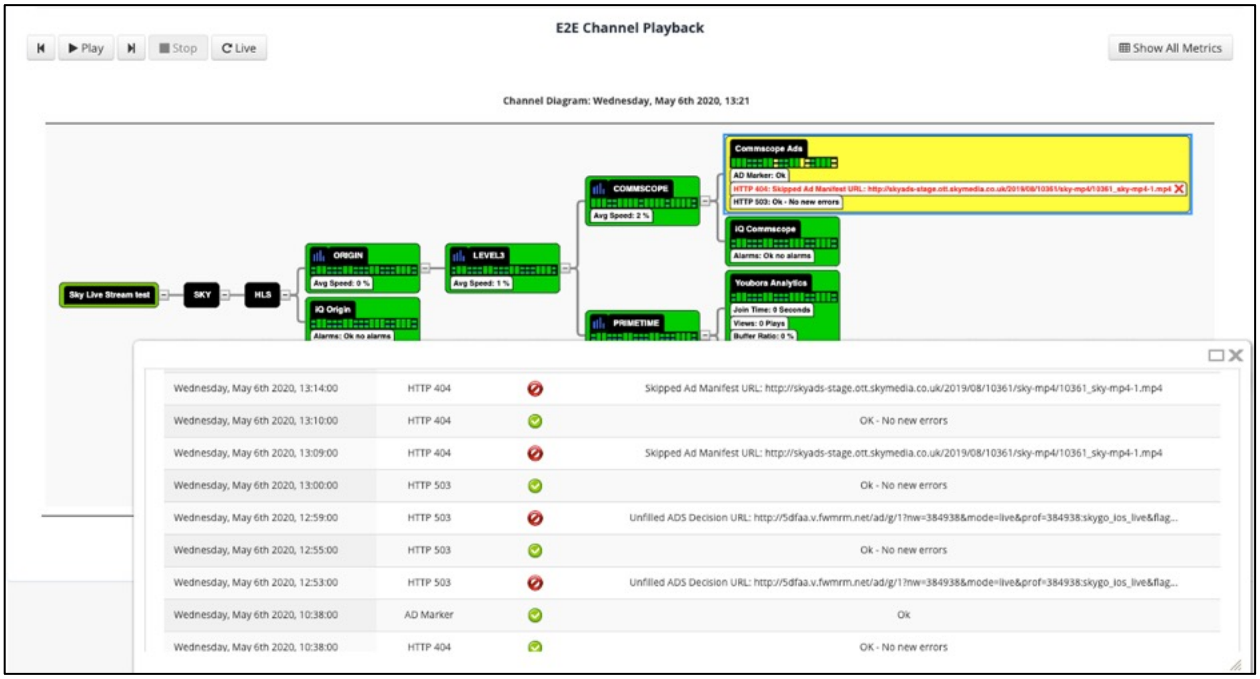

Figure 10 - VirtualNOC End-To-End Delivery Workflow – History

In addition, a simple history is available in the Touchstream VirtualNOC dashboard that tracks all numeric and text based KPIs that have been integrated. In the above example the history of changes in the HTTP 404 error text are shown.

6. POC Results

During the exercise we found that we were able to see actual (simulated) errors occurring in real-time across the many components in POC. By enabling the correct connections with all the key component telemetry systems, we were able to spot key errors and warnings messages that updated our dashboard with the issue. By establishing the correct KPI to monitor, we were able to identify an incorrect ad placement right away by alerting on a “404-http” response on the ad assortment itself. Another issue that was caught is with a malformed manifest, which would have resulted in a failed ad play.

It was clear that having a single plane of glass (view), which allows any operations team with minimal effort, to monitor and diagnose faults in a SSAI service, saves time to fix the problem instead of diagnosing the problem.

7. Conclusion

7.1. What’s Needed for the Future

In addition to the monitoring points which were established, further integrations and metrics could be introduced across other components.

Such as:

- CDN metrics to help establish if there where errors with delivering ad chunks.
- Ad fulfillment systems reporting if there was a drop in predicted ad fill and what ads should have been delivered.
- Quality control of ad creative before it becomes available in the system, especially finding "rough" ads and then action their removal
- Introduce a standard ID to trace ads across the ecosystem, which is actually embedded in the streaming ABR manifests

In reality, the most important area which needs development is the adoption of better monitoring. We believe this can be accelerated via standards and frameworks. If an ad monitoring framework was created that included all the key KPIs, metrics and monitoring points with a common ID, we could then encourage all parties in the Ad ecosystem to adopt it. Enabling better monitoring would not be a complicated bespoke integration and could become a commodity. By reducing the barrier for any party to deploy better monitoring, by no longer needing to build complicated bespoke integrations but by leveraging open standards, would reduce deployments times and complexity.

If more entities are able to spot and see where issues are, then we have more of a chance of fixing them permanently, making "disturbing" ads less complex and user friendly in the streaming ecosystem.

8. Abbreviations

ABR	adaptive bit rate
ADS	ad server
api	application programming interface
AVOD	ad-supported video-on-demand
CDN	content delivery network
DAI	dynamic ad insertion
DASH	dynamic adaptive streaming over HTTP
HLS	http live streaming
HTML	Hyper Text Markup Language
KPI	key performance indicator
MDC	manifest delivery controller
OTT	over-the-top streaming
POC	proof of concept
POPs	Points of Presence
QoE	quality of experience
QoS	quality of service
SCTE/ISBE	Society of Cable Telecommunication Engineers
SSAI	server-side ad insertion
URL	uniform resource locator
VAST	video ad serving template
VMAP	video multiple ad playlist
VOD	video-on-demand

9. About the Streaming Video Alliance

Founded in 2014, the Streaming Video Alliance's charter is to encourage deeper collaboration across the entire online video ecosystem, which will include the development of standards and best practices for an open architecture that will operate across the entire online video value chain. The Alliance is currently focused on identifying issues and solutions related to open architecture, quality of experience, and interoperability. For more information: www.streamingvideoalliance.org.

10. Notice

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Taming Video Spectrum Management For Distributed Access Architecture (R-PHY And R-MACPHY)

DAA Dual Core Management Structure

A Technical Paper prepared for SCTE•ISBE by

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Table of Contents

Title	Page Number
Table of Contents	25
1. Introduction	27
1.1. R-PHY and R-MACPHY	27
1.2. API Interfaces, Other Features and Functions	27
1.3. RPD Lifecycle	27
2. Taming Video Spectrum Goals	27
2.1. Legacy Plant Is the Starting Point	28
2.2. Visualizing the Legacy Video Distribution for DAA	29
2.3. DAA Video Management	30
2.3.1. Managed Video in DAA Structure	31
2.4. Legacy Video - A Deeper Dive	33
2.4.1. SCTE55 (ATSC only)	34
2.4.2. Broadcast Services	34
2.4.3. Narrowcast VOD and SDV	34
2.5. Provisioning Legacy Consumer Premise Equipment	35
2.6. Automation with Linear Source Mangement	36
2.6.1. Broadcast Video	36
2.6.2. LSM Controller	36
2.6.3. Channel Line-ups	37
2.6.4. Video Unified Edge	37
2.6.5. CPE	37
2.6.6. LSM Distribution	37
2.7. Example Progression of Plant Bandwidth	38
3. Conclusions	40
4. Abbreviations and Definitions	40
4.1. Abbreviations	40
4.2. Definitions	41
5. Bibliography and References	42

List of Figures

Title	Page Number
Figure 1 - Visualizing DAA IP Flows from Hub to RPD	30
Figure 2 - Managed DAA Structure	31
Figure 3 - Video Distribution Management Problem	32
Figure 4 - Breakout of Structured Video Distribution Management	34
Figure 5 - DVB In-Band Breakout of Structured Video Distribution Management	35
Figure 6 - Linear Source Management	38
Figure 7 - Legacy Plant BW – pre-DAA and DAA Without LSM Support	38
Figure 8 - Mid-Split Plant BW – DAA Without LSM Support	39
Figure 9 - Legacy Plant BW with Linear Source Management	39

Figure 10 - High Split Plant BW with Linear Source Management 40

1. Introduction

Taming the Video Spectrum really translates to the Operator's ability of "Getting Broadcast Video Out of the Way" to expand Data...without the future crushing Operational constraints or the immediate removal of thousands of legacy devices that continue to satisfy subscribers who do not want change forced upon them (legacy devices that also produce revenue for the Operators).

This paper provides an approach to the challenge of managing Legacy QAM video when deploying Distributed Access Architecture (DAA) to an already deployed diverse group of Customer Premise Equipment with different access/egress paths and user applications. It outlines a solution with enough flexibility that provides the operator automation up to and including a no-touch approach across different legacy System formats [DVB (ITU J.83 Annex A, Annex C) and ATSC (ITU J.83 Annex B)], the inclusion of and moving an Out-of-Band (OOB) or utilizing mixed Annex Modes within the legacy Video Plant (Annex B, Annex C).

Further Automating the Video Channel Line-up Management within the Headend by leveraging switching / VOD protocols, and building an abstraction of transport stream distributions that works for both Distributed Access Architecture and for Legacy QAM / RF Combiner video stream distributions, Operators will be empowered to align video service delivery with operationally usable video provisioning functions to get QAM Video out of the way to support both immediate DAA deployment and the future as network segments incrementally transition from a low-split to high-split architectures.

1.1. R-PHY and R-MACPHY

The choice between Remote-PHY (RPD) and R-MACPHY (RMD) is Operator specific and is primarily driven by the Data side considerations. For purposes of this Video Management discussion, noting that the video services are not dependent on the MAC layer, this choice is beyond the scope of the paper – and for the balance of the paper, RPD is a reference to either Remote-PHY or Remote-MACPHY in the context of Video Management.

1.2. API Interfaces, Other Features and Functions

In a DAA Management System, Northbound API interfaces, equivalent to UI functions, allow for Operator back office functions to control and monitor the DAA system operation. The level of integration is entirely up to the Operator so that RPD / RMD deployment processes, status monitoring and changes can be supported during the lifecycle of the entire DAA System.

Specific discussion of features related to the API Interfaces, High Availability, Failover control, Monitoring and Alarming, etc., while fundamental functions that are supported in a DAA Video Management System are beyond the specific scope of this document.

1.3. RPD Lifecycle

The lifecycle of on boarding an RPD node, from initial configuration through the Principle Core, firmware updates and other lifecycle events are also beyond the scope of this paper. The references to initial configuration are sequential pre-requisites to providing the video configuration(s) to the device.

2. Taming Video Spectrum Goals

The primary goal and motivation of Distributed Access Architecture is increasing Data BW.

If an Operator could, they would simply drag Video along for the ride with Data. The typical Principal Core Data configuration of the RPD is relatively straightforward (meaning 1:1 from Cable Modem Termination point in the Headend or Hub to the RPD in the Node) compared to the "spaghetti distribution" (defined below) of Legacy Video streams across a Designated Market Area (DMA). Legacy Video is literally the elephant in the room as it not only consumes the majority of Plant QAM Bandwidth (BW) but also comes with a shipping container full of difficult to handle baggage (a diverse set of video clients often with older software with limited functionality and limited ability to upgrade).

Legacy Video Consumer Premise Equipment may include multiple generations of DSG Set-tops, RF Set-tops, Digital Terminal Adapters (DTA), and even TVs equipped with QAM Tuners – not all of which are expected to adapt to the needs of an evolving DAA deployment. The understandable desire of Operators is to touch the video side as little as possible; however, the future Plant BW Plan will change over time (for example, a move to High Split) and the Operator will want to retain the set-top box subscribers who are paying for box rental, DVR service and video aggregation fees as well as leveraging the existing ad-insertion system, amounting to many $Billions across the industry, which, in a given footprint is at least partially funding the DAA expansion.

Managing a video spectrum move on a partially deployed DAA node architecture is operationally challenging given the desire to preserve legacy CPE devices and subscriber experience. For example, an inadequate DAA video management structure may drive the changes to a channel line-up level (i.e., above the Narrowcast Video Group to at least the Control Channel level and perhaps higher to the entire channel line-up itself) potentially impacting significant portions of the deployment and leading to unacceptable Opex, schedule and risk (due to high complexity and high cost to implement the change). It is recognized that eventual transition to a High Split Architecture is coupled with a lengthy rip and replace of incompatible legacy customer premise equipment; however, allowing for video distribution from Commercial Off the Shelf (COTS) HW in the headend network and video management to the node allows for a more controlled and granular transition providing relief on each of these areas. This is at the heart of Taming Video for DAA.

DAA Video Management will enable the Operator to manage the DAA Video Distributions across the enterprise to support the remaining Legacy Set-top footprint while also operationally manipulating the plant BW on a partially deployed DAA Architecture on a scale as little as one RPD node at a time – or larger portions up to and including the entire DMA footprint. This structure works equally well for DVB (Annex A or Annex C) or ATSC (Annex B) or a combination of both Annex B and Annex C on the same Plant.

Taming the Video Spectrum primary goal is managing the video distributions and configuration in a way that neither strands legacy video devices in the short term, nor ties an Operator's hands with respect to speed of deploying the DAA Data offering in the short term and optimizing the Data offering and associated Plant BW changes in the long term.

2.1. Legacy Plant Is the Starting Point

The traditional approach to increasing Data BW has been to split nodes. Video is distributed as either Broadcast (always on plant) or Narrowcast (VOD and Switched which is on plant if someone on that segment is tuned). Legacy Broadcast Video is RF Combined over multiple Data Upstream/Downstream

(US/DS) – while the Narrowcast (NC) Video Group may either be a set of QAMs that align exactly with the Data distribution (1:1) or more typically, the RF Combining of NC Video Group may cover 2 or more Data US/DS (e.g., 2 Data US/DS : 1 NC Video US/DS) due to continued node splits. In ATSC Systems, there is a low frequency SCTE-55-x Out-of-Band (OOB) Control Channel that also overlays this video distribution. DAA inherits the Legacy Plant Architecture for Video combining in this regard.

The Legacy Video Services distribution across the complement of RF Combiners may look more like spaghetti. Some video streams are distributed everywhere within the DMA, some to a single ad insertion zone or sub-region, and some to a municipal level (in the US, Public, Education and Government (PEG) channels are must carry and vary from city to city or township to township), all over-layered with the Narrowcast Video Groups perhaps serving from 250 to 1000 subscribers each which may also be segregated in groups by an OOB Control Channel. In a 500k home DMA, with ~500 homes per NC, that could be 500 - 1000 Narrowcast Video Service Groups and perhaps 25-50 OOB Control Channel distributions along with as many as 100 PEG/ultra-local video distributions, several ad zones and of course, the video services that are uniform across a single CAS Controller – all of which may also be repeated if multiple CAS Controllers cover the entire DMA.

In a fully deployed DAA, the RPD node count may grow to 5 or 10 times the number of legacy nodes (assumes pre-DAA Data is 250 to 500 homes per node and target DAA deployment plan is 50 to 100 homes per node).

2.2. Visualizing the Legacy Video Distribution for DAA

An ATSC and/or DVB legacy video channel line-up include Video Services that may consist of a combination of Broadcast and Narrowcast Services (VOD, Switched Digital Video (SDV)). The Broadcast Services may be global (DMA wide), regional or sub-regional (such as Ad Insertion) or ultra-local (PEG) and are assumed to be encrypted centrally for a specific Conditional Access System or Market. In ATSC markets, it may also include SCTE-55 Out of Band Upstreams and Downstreams.

Visualizing the DAA IP flows between Hub/Headend and Node in the figure below, a Video Channel Line-up on the left is realized as the Desired Plant BW on the right.

The Video Edge (UEPI and DEPI) Distributions and CCAP Data IP (UEPI and DEPI) Distributions are shown without a video management structure. The colors represent different distribution flows (aimed at different sets of RPDs) to a single RPD node deployed to a specific geographic location. Through the center of the figure, just to the left of the RPD, the IPv6 Multicast distributions to the RPD, are from top to bottom (1) Upstream SCTE55 RF OOB, (2) Downstream SCTE55 RF OOB, (3) Global / DMA-wide video with multiple MPTS, (4) Regional / Ad-Zone Video with multiple MPTS (video streams delivered to a portion of a DMA), (5) Ultra-local or PEG-Video, (6) Narrowcast Video that may include VOD and SDV, and (7) Narrowcast Data Downstream and Upstream. The RPD converts the complement of streams to specific QAM frequencies of the Plant BW Plan.

The Data is supported by the CCAP. The Principle Core is shown as part of the CCAP and in this simplified view, would be responsible for the entire configuration of the RPD (there is no Auxiliary Video Core yet). Details of the Converged Interconnect Network (CIN) and grandmaster clock are not shown. The Unmanaged Video Edge function creates all the downstream video streams.

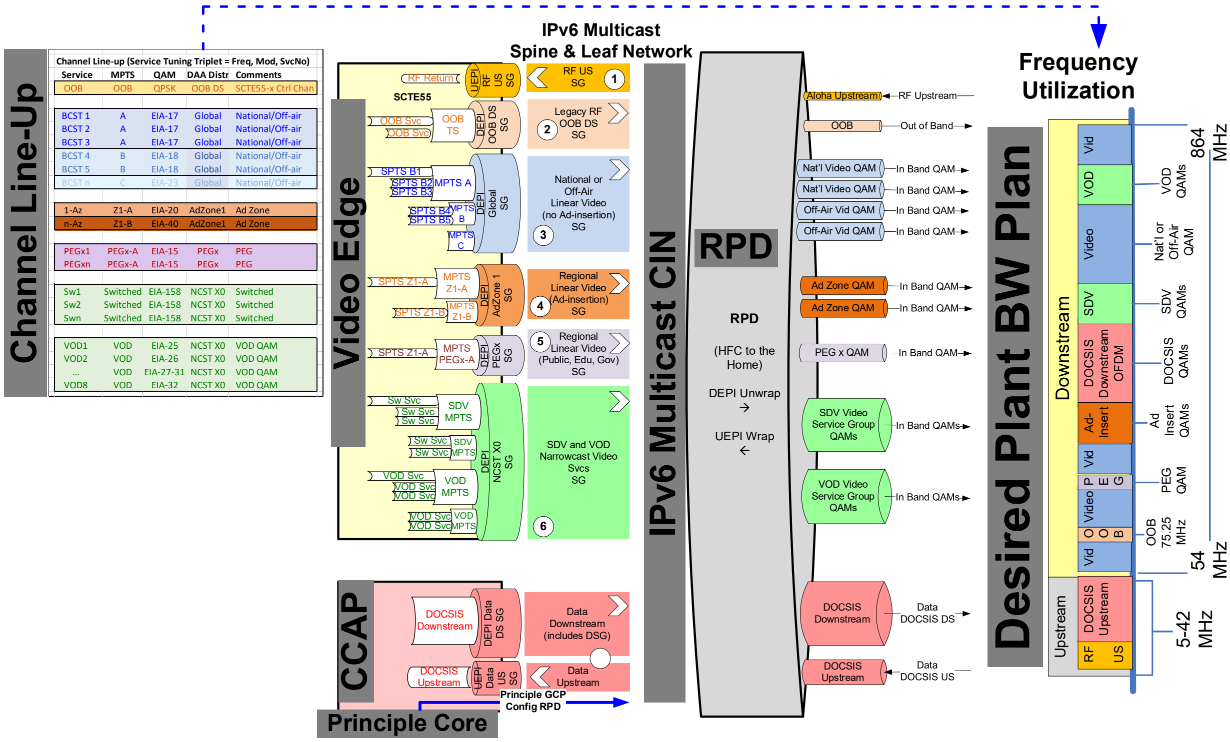

Figure 1 - Visualizing DAA IP Flows from Hub to RPD

2.3. DAA Video Management

A successful DAA Strategy will accommodate an Operator's specific video architecture, channel line-up needs and customer premise video equipment from their starting point to their desired end state. Existing / deployed legacy video applications (Guide, VOD, SDV) and legacy device types (RF and DOCSIS/DSG set-tops, DTAs, OTT/IP Video Delivery Devices and SmartTVs) cause serious implications to supporting video through a DAA transition that can hamper DAA RPD deployment speed, headend network scaling and the actual ability to control Plant BW changes in operationally digestible (small) pieces.

In the structure below, the video functions described (Video Unified Edge, Video Aux Core and Video Topology Management) are Applications that run on COTS HW back in the network and (with adequate BW to the hub) do not necessarily need to take up valuable space and power in the hub itself.

- Video Unified Edge (VUE): Managed Function that builds DAA video for distribution over a Converged Interconnect Network to DAA nodes (R-PHY or RMACPHY)
- Video Aux Core: Auxiliary Core Control Plane function that provides multicast address configurations to RPDs
- Video Topology Manager (VTM): Function that configures and manages the configuration of video transport streams (MPTS), video service groups (DEPI distributions) and sets video multicast configurations for DAA nodes through an Auxiliary Core Control Plane (ACCP)

2.3.1. Managed Video in DAA Structure

In the lower left side of the figure below (light blue boxes), a Video Aux Core (1) and a virtual Manager (2) with dedicated elements for video topology management through the Video Aux Core and an RPD Manager for on-boarding RPDs through the Principle Core function have been added. The main reason for a Dual Core Architecture as an integral part of this DAA Strategy is the specialization required to maintain the legacy video systems, allowing the Operator's existing organization specialization to be leveraged efficiently.

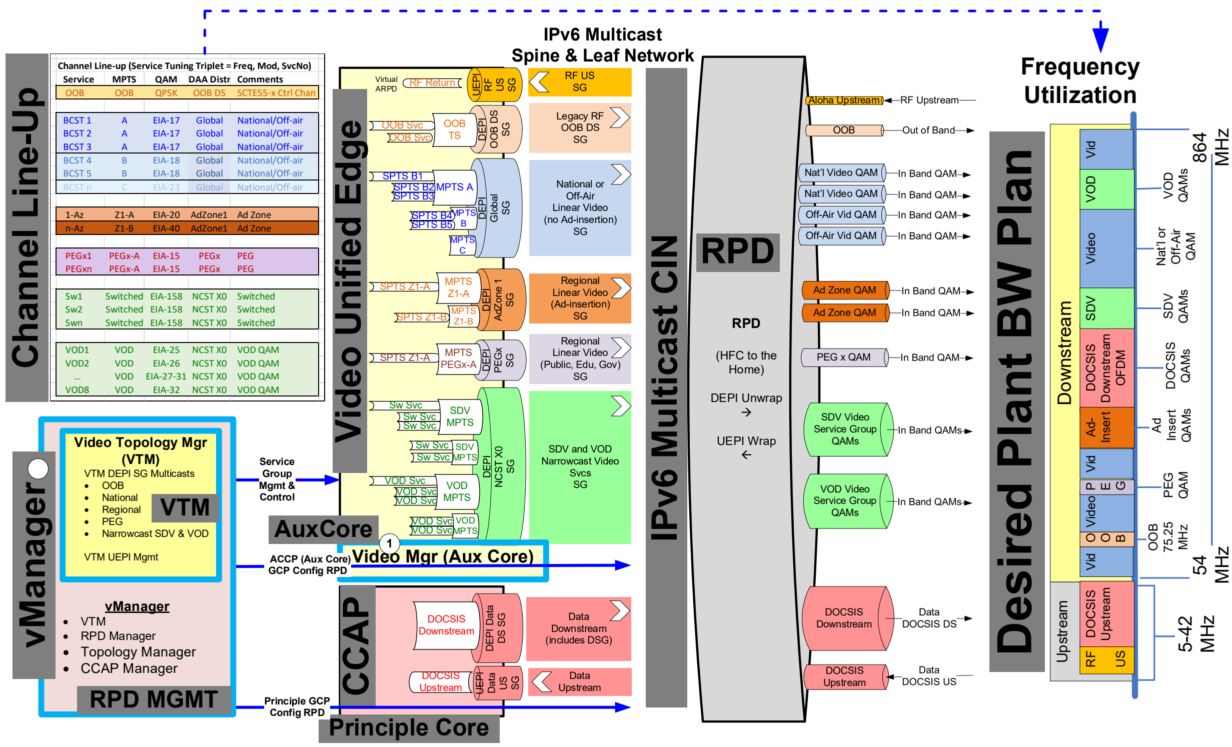

Figure 2 - Managed DAA Structure

An RPD deployment requires the Principle Core provide the initial turn-up. For brevity and to primarily focus on video, it is understood that the Principle Core will connect the RPD to the appropriate services for initial provisioning, IEEE-1588 grandmaster clock, code upgrades, etc. *The Principle Core also identifies the Video Aux Core that will provision and care for the Video configuration.*

At the Video Unified Edge, the encrypted Video Services (which may be combinations of encrypted SPTS and MPTS) must be packaged into Transport Streams, DEPI wrapped and distributed over a CIN to RPDs that are configured to receive the specific multicast distributions to realize a Plant BW Plan that reflects the desired Channel Line-up based on the physical location of the RPD.

The Video Topology Manager configures the Video Unified Edge (defining what video sources are available, how they are packaged into MPTS, what additional is included, and where on the plant frequency each MPTS will fall), assigning the multicast addresses of the Video distribution to be used across the CIN and also provides the specific multicast addresses through the Video Aux Core to the appropriate RPDs to configure the video. Expanding to three RPDs better illustrates the video distribution management problem.

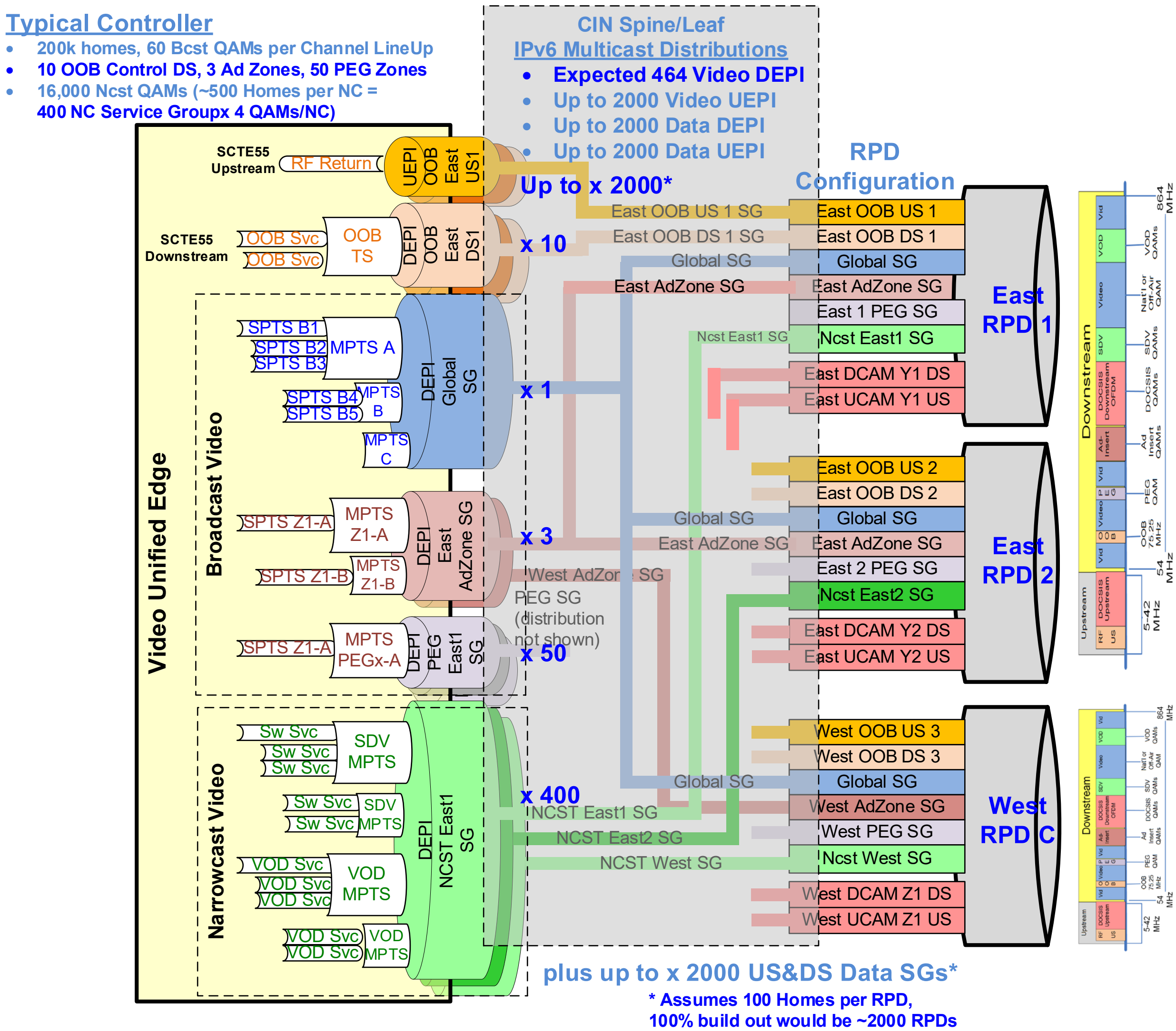

Figure 3 - Video Distribution Management Problem

The number of RF Video Upstreams, Data Upstreams and Data Downstreams will scale directly with the number of RPDs deployed (and Narrowcast Video Service Groups may roughly scale with the deployment); however, even with very few RPDs deployed, the number of Broadcast Video Distributions very quickly saturates a given Controller footprint (meaning each required video distribution is carried on the CIN well before the full build-out completes). In the example illustration, 200k homes passed may have 50 channel line-ups with both common and non-common video distributions. A few RPD deployments will require most or all Broadcast Video distributions as well as the specific associated Narrowcast distributions. In the diagram, OOB and PEG distributions are not shown beyond the first RPD OOB; the East RPDs share an Ad-Zone, but have different OOB, PEG and Narrowcast video. In addition to these different flows, the West RPD is in a different Ad-Zone, but receives the same common "global" distribution.

The figure of three RPDS is illustrative only; an expansion to several more RPDs would illustrate how quickly the problem of managing a channel line-up change or frequency move across more than a few RPDs might be impractical as each node configuration or stream will be touched. If relying solely on the existing configurations, the size of change or the potential for contention poses a significant risk.

2.4. Legacy Video - A Deeper Dive

Legacy Video Topology is fundamentally driven by the Channel Line-up. Management of the Video Service Group (DEPI wrapped video services distributions) includes a structured function designed to minimize OPEX required to manage (build, deploy, and move) Video QAMs on a per RPD Node basis.

The Video Unified Edge must build SPTS into MPTS (physical mapping or using a resource manager leveraging RPC or R6 protocols, or UDP Port Mapping for VOD), insert PIDs, DEPI wrap MPTS into Video Service Groups, and perform a variety of other functions. Note that handling SCTE-55 OOB Control Channel DEPI / UEPI interface may be contained within this function or may be external or via a dedicated path with external equipment.

When an RPD is deployed in a geographic area, with a given Channel Line-up, the group of Video Service Group multicast addresses associated with that Channel Line-up is configured on the RPD through the Video Aux Core. When a second RPD is deployed to the same area, the configuration is repeated (with potential differences in diverse video distributions). Moving a segment of the population of RPDs can be accomplished with the same master multicast definition and assignment process.

In the figure below, the structural management process within VUE is broken out from left to right

- **Define Services:** Available Video Services, including source IP, are defined on the left side which can be imported as a file configuration.
- **Pipe Templates**: are used to minimize Operator input to build empty "pipes" (equivalent to Transport Stream MPTS distribution(s)).
- **Filling the Pipes:** to align with channel line-up tuning triplets (frequency, modulation mode and service number) can be done in several ways to accommodate specific Operator deployments.
    - MPTS Pass Through
    - SPTS Physical Mapping to MPTS
    - Session Protocol (RPC or R6) or UPD Port Mapping (VOD) to MPTS
    - PID Stream Insertion as appropriate
- **Distribution:** Pipes are collected into Service Groups (groups of Transport Streams assigned to the same Multicast with a defined frequency/channel placement) which are made available to the CIN.
- **Assign Service Group to RPD:** from the Video Topology Manager through the Video Aux Core, Video SG Multicasts are configured on the RPD based on the desired Service/Frequency Plan.

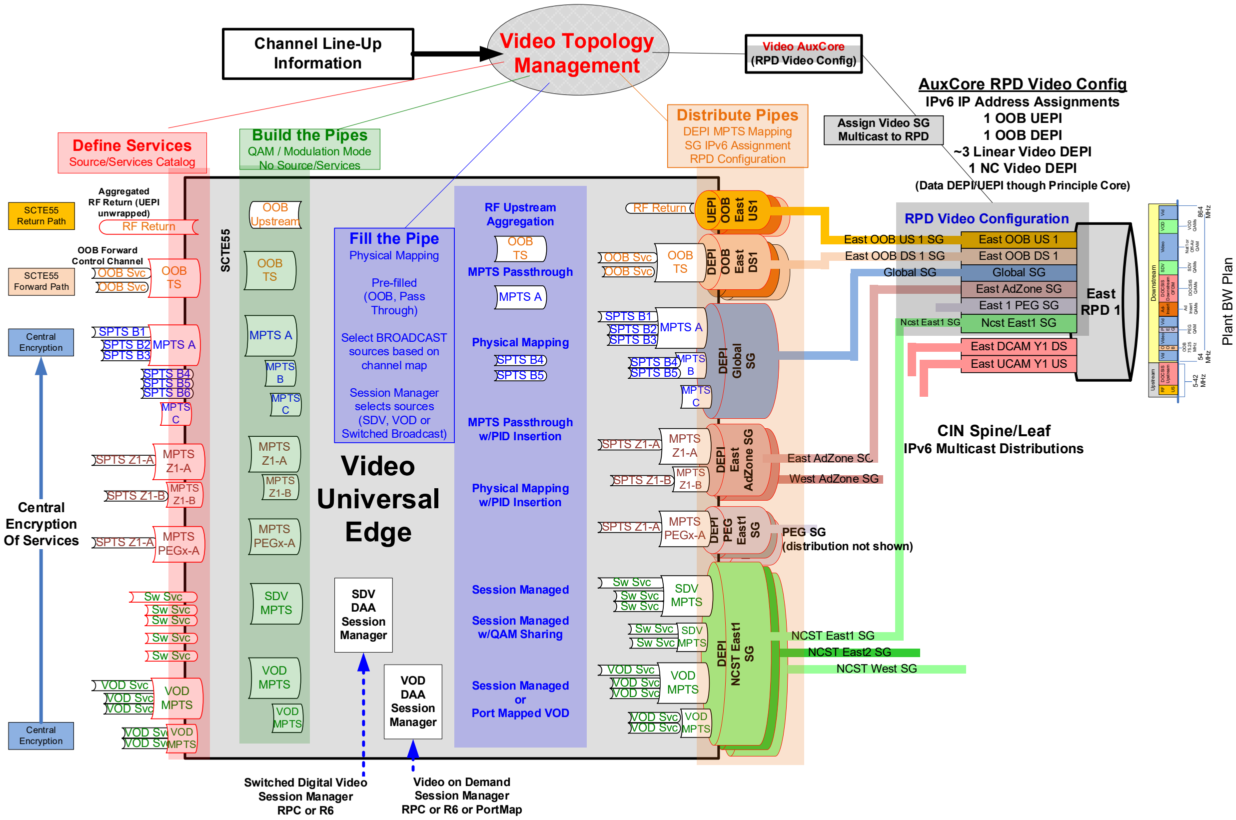

Figure 4 - Breakout of Structured Video Distribution Management

The pipe set-up, stream mapping, DEPI wrapping and ultimate QAM Frequency placement on the plant distribution is under control of the Video Topology Manager. The following potential video sources are configured by the Video Topology Manager in the Video Unified Edge:

2.4.1. SCTE55 (ATSC only)

The forward path could be a pass through MPTS from an existing OOB Downstream Device or the multiplex could be built from individual sources. The RF return paths from individual RPDs can be aggregated to a single IP stream for further processing in the headend.

2.4.2. Broadcast Services

Broadcast Service sources are defined, grouped into MPTS – or the MPTS may be received as a pass through. Either Transport Stream type may require additional service/PID stream insertion based upon the nature of the client devices/CPE. Frequency placement is defined at the video service group output.

2.4.3. Narrowcast VOD and SDV

Services carried within the Narrowcast MPTS(s) are under the control of the VOD Session Manager and/or the SDV Session Manager using standard protocols (RPC, R6) or alternatively, specific VOD function (for example, Port Mapping).

In a DVB System, the breakout is similar. Again, the value is realized at scale as long as there are legacy CPE that receive video QAMs that need to be moved across multiple RPDs as the physical plant evolves. In the figure below, global, regional and local services along with narrowcast VOD are shown.

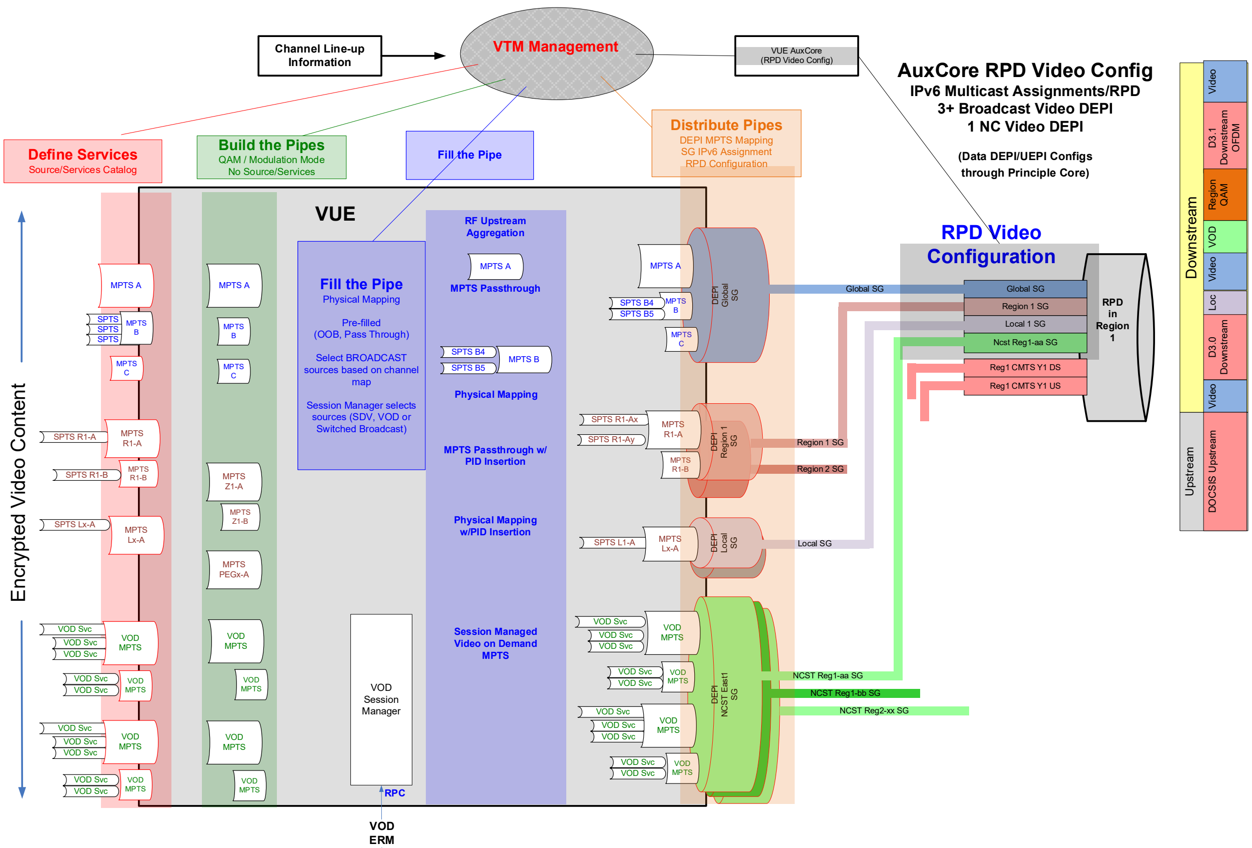

Figure 5 - DVB In-Band Breakout of Structured Video Distribution Management

2.5. Provisioning Legacy Consumer Premise Equipment

Legacy Video Consumer Premise Equipment may include multiple generations of DSG Set-tops, RF Set-tops, Digital Terminal Adapters (DTA), and TVs equipped with QAM Tuners

CPE would continue to be provisioned and operate exactly as they always have; controllers provide channel information (ATSC SCTE65 or Network Information Table and/or other channel related information that provides tuning triplets (QAM frequency, modulation mode, service number) needed for a device to tune a video stream delivered over QAM. In each case, with the exception of devices provisioned over DOCSIS, the provisioning path must be supported by the Video Unified Edge by either passing the control stream as an MPTS or muxing it into the appropriate transport stream and distributing correctly on the physical plant. CPE may include:

- DOCSIS capable Set-tops (i.e., DSG) are provisioned over the DOCSIS path (ATSC and DVB)
- RF Set-tops are provisioned over an OOB Control Channel (ATSC) or over an in-band Control Channel (DVB)
- DTAs are provisioned over an in-band Control Channel (ATSC and DVB)
- Devices with QAM Tuners mirror one of the above

Moving to a high split architecture to increase the upstream data bandwidth necessitates removal of lower frequency dependent OOB Control Channel CPE. With DAA Management, this can be accomplished in a managed, project-segmented fashion; however, even before moving to high split, the management of the video sources may be arduous since the Broadcast Video services delivery are locked to this channel information. The headend systems configuring and/or delivering this information (Controllers, etc.) to the Video Unified Edge must be coordinated with the DAA configuration. This is a necessary inconvenience when the channel line-up is simple, but a significant Operator hardship for more complex line-ups. This problem can be addressed through Linear Source Management (LSM).

2.6. Automation with Linear Source Mangement

Automating the Video Transport Management back towards the channel line-up equipment and CPE provisioning Controllers can be enabled by leveraging the standard RPC and/or R6 protocols used for Switched Digital Video for all Broadcast Services. This applies even if Switched Digital Video is not currently deployed on the Operator's plant.

An SDV Controller enabled for Linear Source Management (LSM Controller) uses the standard protocols to define the services in each multiplex. For LSM broadcast services that are not dependent on CPE tuned to the service, the LSM Controller holds the service in the multiplex distribution (without regard to CPE tuning).

With LSM, a channel line-up resolves to a list of services without regard to frequency placement. LSM can also be used to manage non-DAA legacy QAMs if the Edge QAMs support the standard protocols (most do). Channel line-ups can be changed without the need for spreadsheet coordination; LSM eliminates coordinated human intervention across diverse and cumbersome systems.

2.6.1. Broadcast Video

The entire Broadcast Line-up is set up to be Switched Video in the Provisioning / CAS Controller and specific CPE can be addressed with specialized functions in the Video Unified Edge. If devices (such as DTAs) are on the plant or if the services require to be always on, those Services will be marked in the SDV System to remain always on and not dependent on tuned channel information coming back from the CPE. The entire video distribution is pushed into the specific Narrowcast Video Service Groups which are expanded to include the MPTS formerly part of static Broadcast distributions. The placement of a given service is not static from one Narrowcast Group to another.

2.6.2. LSM Controller

As just mentioned above, the SDV System requires a function to continue sending designated video services as if there are boxes tuned to the service even if none report. This allows forcing the distribution of both DTA and PEG (must carry) services for which there would potentially be no tuned service indication coming back from CPE to the SDV Controller. The entire channel line-up is configured for each Narrowcast Video Service Group distribution as a list of services. The LSM places the video services using the optimization logic for normal SDV Services to define frequency and service number, and it also includes specific placement of the OOB Control Channel (if one exists)

2.6.3. Channel Line-ups

Local video distributions across a DMA are still handled via different channel line-ups per geographic area. Channel line-ups are set to indicate that all video services are switched (no longer consistent between narrowcast service groups). This allows the RPC or R6 Protocol to place all video services just as it would for an SDV or VOD Service, within an expanded Narrowcast Video Service Group for distribution to the RPD. The RPD will be configured for the Video RF Upstream (RF Return) and Video Narrowcast Downstream. The OOB delivered channel line-ups are provided without the channel frequency and service number to the OOB CPE. OOB CPE depend on the SDV function to tune the services. The in-band delivered channel line-ups are modified to be consistent with the service number and frequency delivery in the specific narrowcast video service group.

2.6.4. Video Unified Edge

The VUE will adjust any channel maps (STE 65 or DVB cable delivery descriptor and service list descriptor) passing through the in-band narrowcasts to reflect a normal broadcast channel placement consistent with where the services are placed within that set of narrowcast video QAMs. The VUE output can either be DEPI wrapped for DAA or IP for delivery to a legacy non-DAA Edge QAM(s) or CCAP Video QAM(s).

2.6.5. CPE

CPE devices in each geographic area would still be configured with a channel line-up or channel map identifier and the normal channel information distribution would occur via SCTE65 or NIT and related DVB system descriptors. DOCSIS and RF set-tops that do not use an in-band Control Channel are enabled with a Switched Digital Video client (recognize that for most legacy set-tops, even if the client is not currently deployed in a system, this is largely available and supported). In-band CPE, such as DTAs, continue to use the clients already deployed (no changes). Provisioning of CPE occurs using the standard process adopted by each Operator using the existing back office and billing system functions. The service tuning of the CPE client will match the physical distribution – either as an SDV client or as a standard tuning of the service.

2.6.6. LSM Distribution

As shown in the figure, distribution may be DEPI wrapped and delivered over DAA. Distribution may also be to existing Edge QAMs and RF Combining Networks. If distributed through a CCAP with the High-Speed Data on a single high density port, no RF Combining is needed.

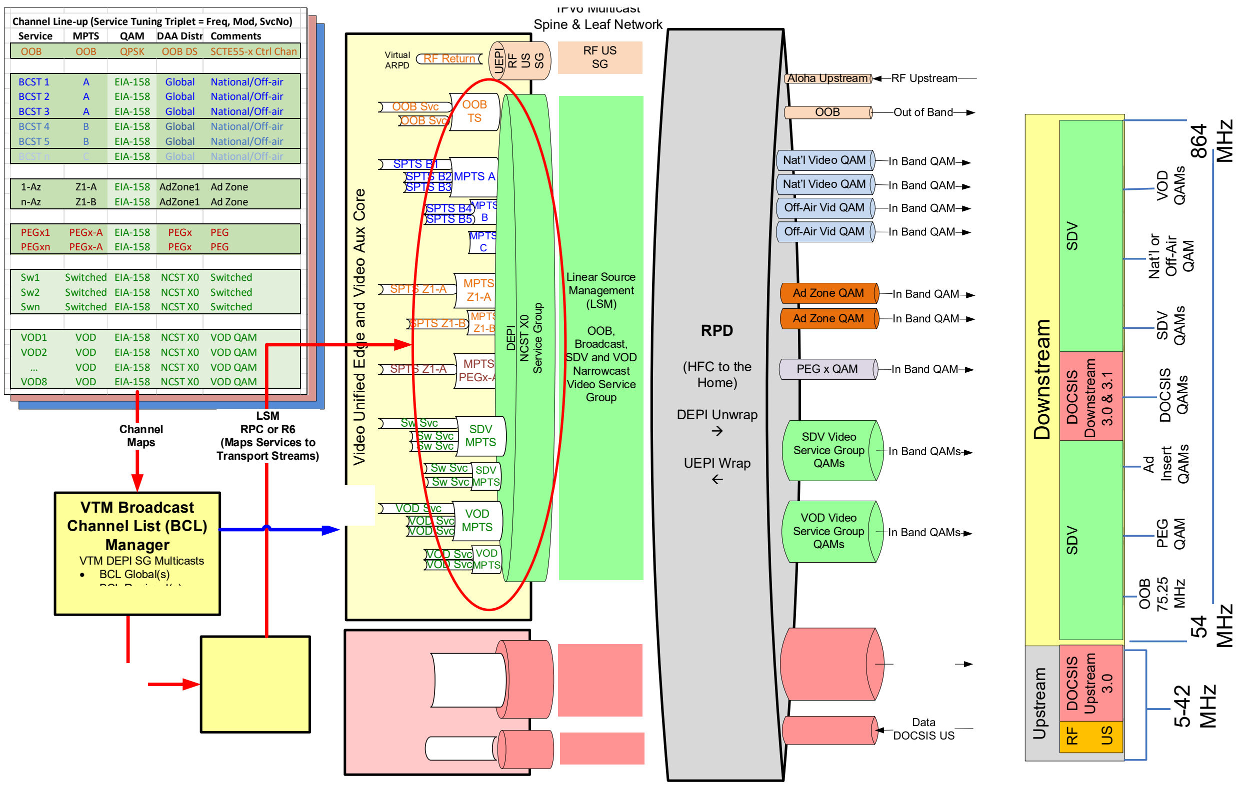

Figure 6 - Linear Source Management

2.7. Example Progression of Plant Bandwidth

The following illustrates progression for one channel map distribution to one DAA Node as more BW is reclaimed from Video to Data:

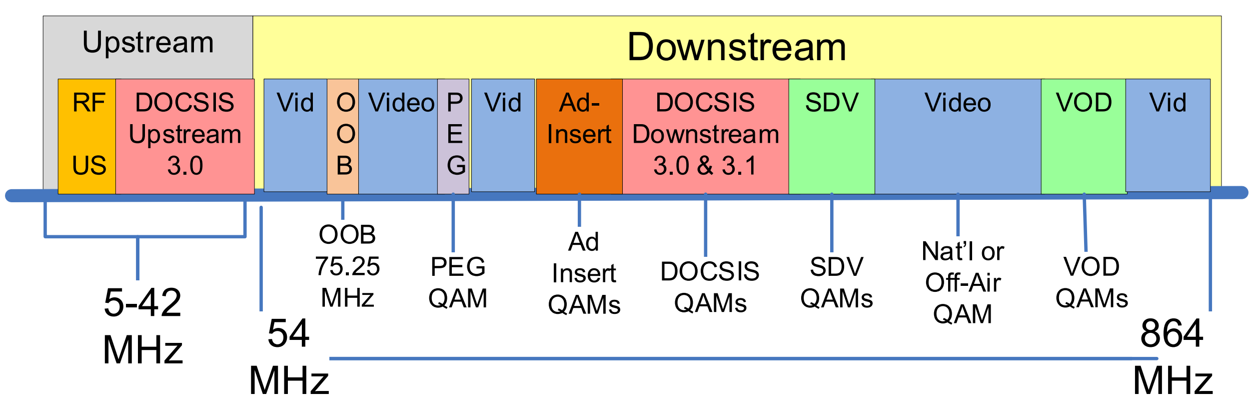

Figure 7 - Legacy Plant BW – pre-DAA and DAA Without LSM Support

Initial DAA support mirrors the current Data and Video deployment. In an 860MHz Plant, 5-42MHz is used for the upstream and 54-864MHz for the downstream. In this example, an SCTE55 OOB Control

Channel is located at 75.25 MHz. This depiction has DMA wide, Ad-zone and ultra-local PEG distributions; Data has DOCSIS 3.0 Upstream and both DOCSIS 3.0 and 3.1 downstream support.

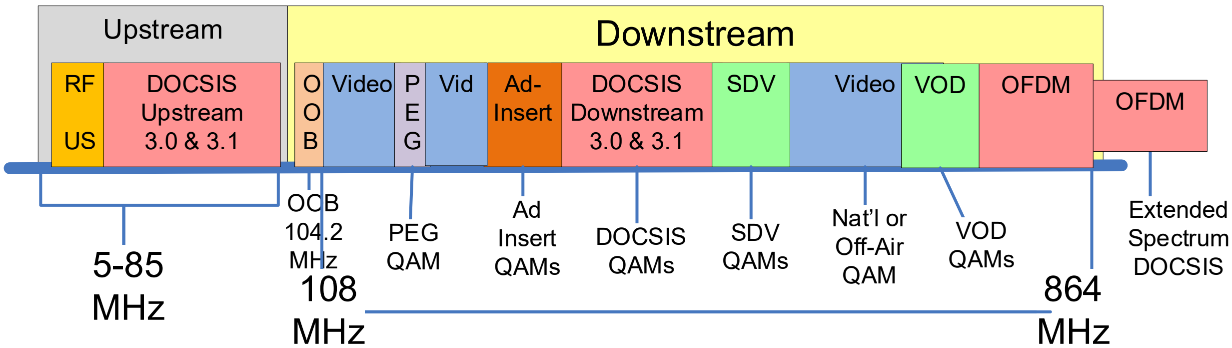

Figure 8 - Mid-Split Plant BW – DAA Without LSM Support

Mid-Split provides for more upstream Data bandwidth (5-85 MHz) and more downstream Data bandwidth requiring the movement of the OOB Control Channel and other video QAM movement to clear the lower frequencies. The illustration shows an optional use of extended spectrum as potential path to increase Data downstream. This has no impact on the need for managing video and is shown for illustrative purposes only. This transition may occur after a substantial number of DAA Nodes have been deployed driving a risk-minimizing desire to manage the movements on selected nodes versus affecting the footprint associated with an entire channel line-up (impacting both DAA and non-DAA footprint).

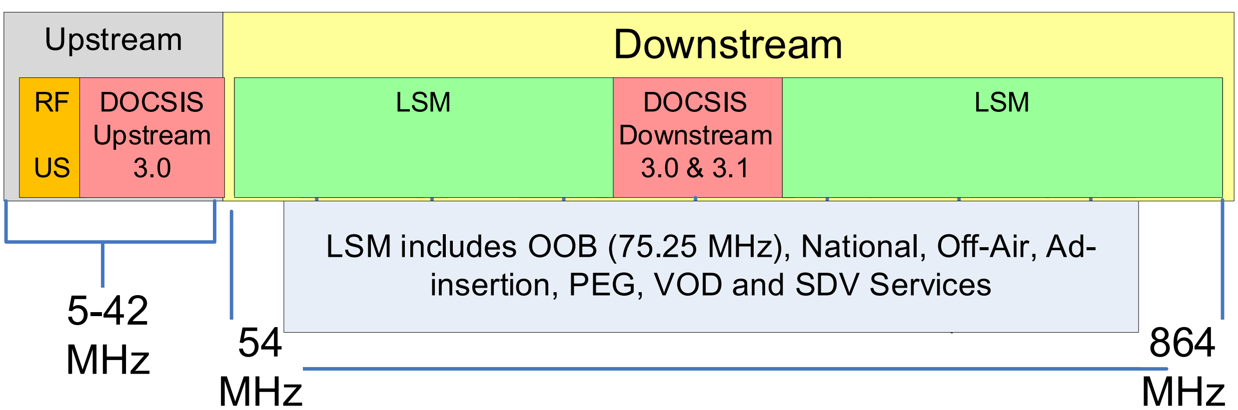

Figure 9 - Legacy Plant BW with Linear Source Management

Alternatively, the first conversion may leverage Linear Source Management to deliver the identical set of services as pre-DAA. Video Services are managed at each Narrowcast Video Service Group level.

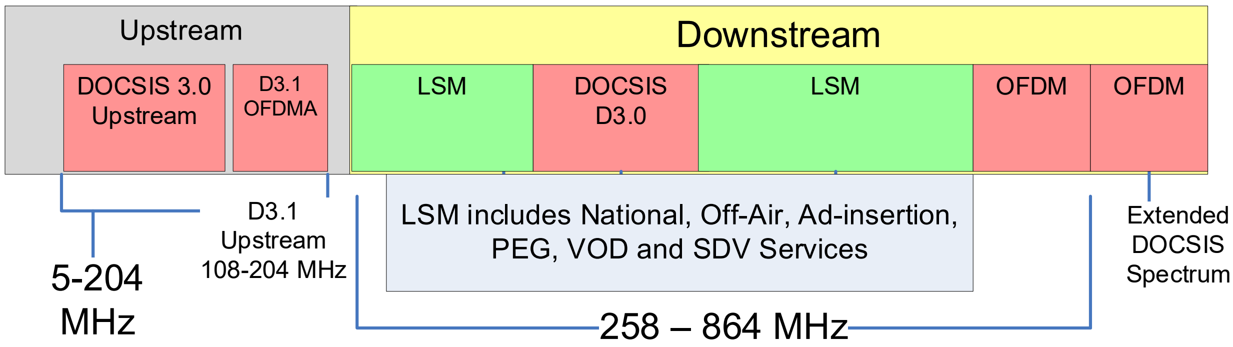

Figure 10 - High Split Plant BW with Linear Source Management

High-Split with Extended DOCSIS with Linear Source Management eliminates the OOB Control Channel (this can be done on a node by node or larger area).

The above figures are merely illustrative. Regardless of the specific transitions, the movement of video QAMs to accomplish desired changes require more granular control of video distribution. Getting video out of the way is hard.

The need for more Data BW will not wait. Managed Video within a DAA context includes the portions of the plant that have not yet transitioned to DAA. The video management function must be deployed with the DAA nodes in order to manage the Risks, manage the costs and enable the speed of BW changes.

3. Conclusions

DAA Video Management will allow an Operator to progress the physical plant through DAA related changes in a planned and programmatic fashion. Absent an operational capability to manage video, the highest risks to the data progression includes:

- Velocity Risk: limiting data expansion speed (i.e., speed of node deployment),
- Schedule Risk: extended timelines to move video and reclaim bandwidth, potentially to the point of operational paralysis
- Breadth Risk: too broad a footprint of stranded legacy video CPE to effectively transition (and retain all) existing subscribers

4. Abbreviations and Definitions

4.1. Abbreviations

ACCP	Auxiliary Core Control Plane
API	Application Program Interface
BC	Broadcast
CCAP	Converged Cable Access Platform
CIN	Converged Interconnect Network
CMTS	Cable Modem Termination System
COTS	Common Off the Shelf

CPE	Customer Premise Equipment
DAA	Distributed Access Architecture (R-PHY Node and R-MACPHY Node)
DEPI	Downstream External PHY Interface
DMA	Designated Market Area
DOCSIS	Data-Over-Cable Service Interface Specification
DSG	DOCSIS Set-top Gateway
DTA	Digital Terminal Adapter
DVB	Digital Video Broadcasting
IP	Internet Protocol
IPv4	Internet Protocol, version 4
IPv6	Internet Protocol, version 6
MPTS	Multi Program Transport Stream
NC	Narrowcast
OOB	Out-of-Band
QAM	Quadrature Amplitude Modulator
QPSK	Quadrature Phase Shift Keying
PEG	Public Education Government
RMD or R-MACPHY	Remote Mac Device
RPD or R-PHY	Remote Phy Device
SDV	Switched Digital Video
SG	Service Group
SPTS	Single Program Transport Stream
STB	Set-top Box
UEPI	Upstream External PHY Interface
VOD	Video On Demand
VTM	Video Topology Manager
VUE	Video Unified Edge

4.2. Definitions

Downstream	Information flowing from the hub to the node / CPE home
Switched Digital Video or SDV (Resource Manager)	A system that supports the ISA RPC or NGOD R6 & D6 or CableLabs protocols to an edge device
Upstream	Information flowing from the node / subscriber CPE to the hub
Video Topology Manager (VTM)	Function that configures and manages the configuration of video transport streams (MPTS), video service groups distributions and sets video multicast configurations for DAA nodes through an Auxiliary Core Control Plane (ACCP)
Video Unified Edge (VUE)	Function that builds DAA video distribution over a Converged Interconnect Network to DAA nodes (R-PHY or RMACPHY)

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Remote-PHY Specification CM-SP-R-PHY-I14-200323 Cable Television Laboratories, Inc.

SCTE55, Out of Band Transport Specification

SCTE65, Service Information Delivered Out-of-Band for Digital Cable Television

Driving Adoption of IP Edge Devices

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Table of Contents

Title **Page Number**

Table of Contents 44
1. Introduction 45
2. Drivers 45
   - 2.1. Programmer 45
   - 2.2. Affiliate 47
   - 2.1. Programmer and Affiliate 47
3. Issues and Alternatives 47
   - 3.1. Latency 48
   - 3.2. Transcoding 48
   - 3.3. Graphics 48
   - 3.4. Reliability 49
   - 3.5. Synchronization Between Local and National Feeds 49
   - 3.6. Security 49
   - 3.7. Bandwidth 50
4. Implementation 50
   - 4.1. Programmer 50
     - 4.1.1. Transition 51
     - 4.1.2. Federated Rights Management 51
     - 4.1.3. Compression 51
     - 4.1.4. Satellite vs IP 52
     - 4.1.5. Production 53
   - 4.2. Affiliate 54
     - 4.2.1. Acquisition 54
     - 4.2.2. Advertising 54
5. Implementation questions 57
   - 5.1. Programmers 58
     - 5.1.1. Questions 58
     - 5.1.2. Future considerations 58
     - 5.1.3. Advertising 59
   - 5.2. Affiliates 59
     - 5.2.1. Questions 59
6. Conclusions 59
7. Abbreviations and Definitions 59
   - 7.1. Abbreviations 59
8. Bibliography and References 60

List of Figures

Title **Page Number**

Figure 1 – Addressable advertisement spectrum 55

Figure 2 – Unused switched video spectrum 56

Figure 3 – Addressable switched video spectrum utiliized 57

1. Introduction

A new development in distribution is now taking shape, smartly leveraging many of the investments made by both multichannel video programming distributors (MVPDs) and programmers to adapt to IP streaming models for customer retention and as alternatives to satellite distribution. Some MVPDs are starting to move towards an adaptive bitrate (ABR) IP centric solution and supporting legacy set tops at the edge with ABR to transport stream (TS) conversion. MVPDs that have deployed switched broadcast can use their available narrowcast bandwidth to microcast networks to subscribers. Meanwhile, programmers that have relied on satellite distribution will be facing the challenge of C Band spectrum being reassigned to 5G.

Since most programmers are already producing ABR content for their TV Everywhere feeds, with proper encryption and rights management these feeds can be used by the MVPDs, eliminating their encoding and long tail storage costs. Many networks can also eliminate broadcast chains as a significant amount of content can be pre-encoded with broadcast automation provided by creating a simple manifest file. It is also possible that live events can be treated essentially the same way with a live manifest combined with pre-encoded content. This opens up opportunities for creating spin-up special event networks, blackouts and alternate content opportunities and makes addressable advertising on linear simple and inexpensive. Special sports events can also be broadcast in 4K/HDR as ABR can be delivered direct from the venue and be picked up for legacy distribution with the same edge devices.

This paper will explore the emerging methodology for fragmented live and on-demand content distribution from the programmer thru the entire distribution chain including legacy broadcast and cable networks. Edge ABR to TS devices will allow both programmers and affiliates to move completely into the segmented file-based delivery infrastructure and eliminate much of the MPEG transport stream distribution from their infrastructure. In addition to there are many other opportunities for programmers and affiliates to reduce costs and drive new revenue sources with this approach.

2. Drivers

Both programmers and affiliates can achieve significant cost savings and revenue enhancement by moving to a segmented IP infrastructure. They can realize even greater benefits by working with each other to maximize the gains from their investment.

2.1. Programmer

Many programmers today utilize a traditional linear delivery infrastructure, typically using satellite compressed statistically muxed multi-program transport streams yet have also introduced TV everywhere services using adaptive bit rate segmented delivery over HLS or DASH. The satellite delivery model, while being cost effective and reliable, is under attack from multiple fronts including:

1) Spectrum reallocation. The FCC will be auctioning some of the reliable C band spectrum for 5G use. While the Ku-band alternative could be used, it suffers from atmospheric issues but may serve as one conduit to get packets to a headend and use segmented IP as backup or error recovery. Alternatively, if C-Band spectrum is just reduced, more efficient video and audio codecs along with a software edge receiver that can use IP and RF inputs may also provide a solution. This way the transponder footprint can be minimized by moving some networks to IP delivery and only keeping the most widely distributed networks on satellite.

2) Direct Fiber. Installation of uncompressed or mezzanine (lightly-compressed) level direct fiber feeds to the larger MVPDs is increasing. For many programmers getting the top 10 to 20 affiliates on fiber will reach over 90% of subscribers. These fiber links could also be used to send ABR files to the affiliates without using CDN bandwidth. Programmers are also making their feeds available at many of the fiber hub sites (CoLo) in cities across the US. If the affiliate has fiber to the CoLo then a simple cross connect is all that is needed.
3) Fiber redistributors with a defined video distribution network that aggregate and redistribute programmers' feeds using various IP methods. These redistributors are also likely to receive a mezzanine feed.
4) New technology or vMVPDs service providers offering smaller affiliates a way to deploy IP either incrementally or completely by subscribing to a remote headend service, eliminating the need for the affiliate to receive satellite.
5) Ongoing economic pressure. Whenever a technology change such as a new codec (HEVC, AV1, VVC) or modulation such as DVB-S2X is implemented, programmers typically have to buy their affiliates new receivers, and many have over 3000 receive sites requiring multiple receivers. This can be extremely expensive depending on the channel count and transcoders needed. When satellite transponder space gets more limited due to spectrum reassignment, then codec and modulation upgrades may be required to operate in the smaller bandwidth. There is no guarantee that after spending those funds that the FCC may issue subsequent rulemaking and repurpose all of the C band spectrum.
6) Limited space for new product introduction. If the programmer wants to broadcast channels or events in 4K, HDR, WCG, there may not be room on the current satellite infrastructure for such bandwidth intensive products. There may be plenty of CDN bandwidth available and if it is only used for high profile events, processing could even be spun up in the cloud.

Programmers can replace receivers with off the shelf servers or virtual machines and software to convert the segmented input to a transport stream of the correct codec/bitrate/resolution for that affiliate. They can also use a federated rights management implementation on their TVE ABR feeds to work with the affiliates edge devices and the direct-to-consumer TVE feeds. This combination would allow the programmer to eliminate or greatly reduce their satellite footprint and reduce production and distribution costs significantly.

Programmers are also looking at using incremental revenue from addressable advertising capabilities with IP delivery to more than offset the expense of deployment. Many are currently using manifest manipulation for addressable advertising for millions of TVE and OTT viewers, it would be inexpensive to add in 3000 (or more for finer geographic zone ability) endpoints to provide MVPDs with unique manifests.

Most of the cable networks have no live component and no graphics overlay requirements. These networks could literally just exist as files on the programmer's origin and the "live" network feed is created simply by generating a live manifest. Some vendors already have the capability to inject audience measurement watermarks and could do this on the edge receiver. As these are all pre-encoded feeds a high-quality multiple pass encode and package can be used. For some networks that want to add real-time graphics, that ability can be implemented on edge devices including the ABR to TS devices, as well as phones and laptops.

2.2. Affiliate

In order to remain competitive, MVPDs have become internet service providers and are installing significant internet backhaul bandwidth to their headends. Subscribers are using OTT and TVE video services that are bandwidth intensive and largely unmanaged. If all viewers were simultaneously using OTT services this would present a much higher backhaul load then a managed, cached, system.

Some affiliates are moving towards an all IP infrastructure as they need to support bring your own device (BYOD) such as phones (iPhone, Android), tablets (iPad, Android), commercial set tops (AppleTV, Roku, Fire, Android) and connected TV's. Affiliates also have a large number of legacy set top boxes deployed (and generating revenue) that rely on an MPEG transport stream over QAM with some older boxes only supporting MPEG2.

IP MVPD ABR to TS edge devices allow the Affiliate to modernize their plant for BYOD while continuing to support their legacy set tops. It also allows for new revenue opportunities in addressable advertising for both the affiliate and programmer.

Another cost savings can be had by using the programmer's high quality first generation encode and eliminating the need for the affiliate to re-encode the content. This can be used for networks with no ad or other content insertion requirements that may be at a different bitrate or resolution. There are many networks broadcast today for which this is very achievable.

If the affiliate requires additional codecs such as MPEG2 for legacy set tops, then just one additional generation transcode needs to be done. This endpoint transcode can also allow more flexibility for advertising as all of the ads do not necessarily have to be the same codec, resolution and bitrate. They can also transcode for the lowest common denominator in that ad zone or microzone being fed by the edge device. For instance, if all of the boxes in that zone are AVC capable, then an AVC transcode can be employed, saving downstream plant bandwidth.

If the expense of the transcode box can be kept low enough, then more can be deployed. This would allow for smaller service groups and depending on the number of viewers, many channels would effectively be unicast and could enable personalized programming and addressable advertising. Additionally, with small enough service groups, people that live in the same neighborhood tend to have similar demographics and a "microcasting" set of ad decisions can be made.

2.1. Programmer and Affiliate

The software segmented to transport stream solution for the programmer and the affiliate is essentially the same server or virtual machine and software. By having these devices work with standardized interfaces and security, there would be significant mutual benefits to both parties. The programmers can still create their content in linear or on demand fashion at significantly less expense. The affiliates can just utilize that content directly to their legacy and IP subscribers. Both parties can increase their advertising revenue by providing an enhanced addressable capability.

3. Issues and Alternatives

There may be some concerns implementors have with segmented IP delivery. This section will discuss some of these concerns and how the risks can be mitigated.

3.1. Latency

Both HLS and DASH have introduced low latency streaming modes. This comes at the expense of reliability, but that may be managed in other ways. For Affiliates with direct fiber connections there should be no bandwidth issues on getting the sub-segments from programmer to affiliate with a low bit error rate.

Because of the reliability issues, the low latency modes should only be used when low latency is required, likely high profile live sports events or online betting. If a sports event takes a separate path from the venue, through the CDN to the subscriber, this can be managed as a low latency stream while the normal network feed uses reasonable buffering.

As most of the low latency methods replace the low latency chunks with normal duration segments once available, any viewers that are not at the live play head due to pausing should receive the non-low latency segments.

3.2. Transcoding

Programmers may want to deliver the highest quality feed at the lowest possible bit rates for reduced CDN costs. If the affiliate needs other codecs to send the feed to legacy set tops the content can be transcoded once on ingest from the programmer or at the edge devices if that gives additional capabilities such as localized ad insertion.

Programmers should determine what that highest quality really needs to be on the segmented IP delivered content. If high quality mezzanine feeds are being used to deliver to 90% or more of the end subscribers, then a lower resolution to save bandwidth costs for the programmer and ingest bandwidth for the affiliate. Most news networks would most likely run fine at 720p30, program or movie-oriented channels may desire 1080p30 for some programming 720p30 for other content. Sports content may want 1080p60 or UHD HDR formats. The option to switch resolutions per program can reduce CDN costs and the programs themselves can be encoded so that a per-segment quality is used and the max bitrate/resolution/frame rate is only as high as required.

With FFMPEG, Intel QuickSync, or Nvidia NVENC enabled transcoding, dense, good quality AVC and MPEG2 HD and SD transcodes can be obtained from fairly low complexity servers. Many of the current vendors that would provide a complete system can also use these capabilities in their software. There is a tradeoff with encode quality and speed as many vendors proprietary implementations can perform better, but the affiliate may not need the absolute best quality. Edge transcoding would also allow programmers to turn off legacy SD and HD feeds (typically MPEG2). This is in comparison with current satellite receivers that use hardware transcoders that cannot adapt to new codecs and transmission techniques such as resolution and frame rate variations.

3.3. Graphics

It is possible with transcoding to insert graphics into the affiliates stream at the edge device. In most networks this is done on origination or when the content is pre-encoded and on the origin server with all graphics already embedded.

Many vendors currently support HLS graphics overlays that can be rendered on a mobile player or the edge receiver/transcoder device. Vendors have also demonstrated the ability to insert logos and graphics in to compressed streams without re-encoding, although a re-encode may allow for more capabilities. There may need to be some standardization of sending graphics and overlays in manifest files.

An example would be some news networks that have a phone application that creates all of the on-screen graphics. For this feed the networks actually had to remove the broadcast graphics from the screen to be able to insert new dynamic overlays.

3.4. Reliability

While smaller affiliates may need content delivered over an internet pipe, many of the larger affiliates will have CoLo access or can create dedicated fiber feeds to the programmers. While this may be the top 20 affiliates at 30 channels each per programmer, so only 600 delivered channels and will not reduce CDN costs that much, it can greatly improve the reliability of delivering the feeds to 90% or more of the subscribers.

Most programmers will publish to redundant origins, multi-path CDNs, east/west coast or even international sites. Many of the devices today can dynamically use alternate CDN's or publishing locations automatically. Some are even smart enough to determine mid segment if they should request from another source. IP delivery will also eliminate the seasonal satellite outages.

Additionally, methods such as forward error correction, Aspera, Zixi, SRT and RIST can be used to increase the reliability of segment delivery.

Some operators still have concerns with software products running with 24x7 reliability. While there are many software systems that are in use at most programmers (encoders, packagers) there seems to be some reluctance to deploy this technology at affiliates. This reluctance should be managed with proper testing, deployment and remote support. The remote systems software must be well designed, robust and well tested. The remote systems should also be centrally managed and well supported. Larger affiliates can run multiple ingest servers for additional redundancy.

3.5. Synchronization Between Local and National Feeds

Video is inherently a linear process that runs at a fixed frequency and latency which will have fixed delays. There should be no issues syncing local to national feeds, even live, as they are simply manifest creation tasks. Since ad and program cues may be embedded in the streams as SCTE 104 or 35 and moved to the master manifest file as tags or emsg blocks, switching between segments at the appropriate time should just be a matter of manifest manipulation.

3.6. Security

A positive capability is that with this method "Receivers" at the affiliates are now accessible on the internet and can be managed by the programmer. Today, once a receiver is shipped to an affiliate, it enters a black hole and programmers have no definitive idea where it is located, if it is racked, receiving, has problems or is at some other operator and authorized for channels they are not contracted for. Internet receivers can phone home and update status, software and security. You can also use two-way encryption methods that are easily updated if compromised.

The corresponding negative is that "Receivers" at the affiliates are now accessible on the internet and can be hacked if not properly secured. The servers need to follow all best practices for an internet connected device including the following basic capabilities but need an extensive security audit as well.

1) Very limited and typically non-standard ports opened, or no inbound ports open and the devices phone home to set up the connection.
2) Up to date Operating System
3) Only the absolute necessary packages for operation loaded and running. No other packages running or located on the server.
4) Since an accurate clock may be needed to recreate broadcast at the proper time or switch to alternate sources, a secure time protocol needs to be used. This is a security attack vector as well.
5) At least two ethernet ports for an internet facing and an internal "trusted domain" port.

Security must be designed in from the start to get full advantage of an IP internet connected receiver.

Another option would be to have the IP Edge receiver add additional forensic audio or video watermarking to be able to identify the source of pirated content. This can also be done by creating a unique content version that can be added to individual manifests to identify the offending receiver. There are many other techniques as well using A/B feeds/manifests that are randomly sent to each receiver to create a unique pattern that can be identified.

3.7. Bandwidth

There is some concern over smaller MVPDs not having enough backhaul bandwidth to bring in programmers over IP. While this might be the case in a shrinking subset of systems, most MVPDs also are the major internet service provider in the area. By using the best ABR compression techniques, programmers can help the affiliates minimize the backhaul usage.

4. Implementation

4.1. Programmer

There are many things to consider when replacing satellite delivery by IP methods. They include:

- compression
- networks per receive site
- total networks
- east/west coast feeds
- blackouts
- advertising
- affiliate contracts
- system age
- replacement timing

With some satellite uncertainty, the current state of IP delivery technology should allow for a better, cheaper upgrade cycle that will no longer strand the programmer in a limited system that can't be upgraded. Programmers will have a new system that can perform incremental upgrades to support new business needs without requiring a forklift replacement of thousands of receivers.

4.1.1. Transition

One method to perform the transition to IP segmented distribution would be to put one of the software edge Integrated Segmented Transcoders (IST) in front of the current satellite uplink infrastructure. Some of the IST devices are capable of creating a stat-mux output that can be fed directly to the sat encryption and CAS servers and to the uplink, removing the current encoders from the chain. There would typically be two devices which could sit at the satellite uplinks for redundant failover.

If the programmer would be replacing the current receivers with IST devices, then they could also upgrade to DVB-S2X transmission and depending on their satellite contracts, minimize the transponders they use.

The IST would have to re-insert the SCTE 35 cues from manifest messages. The IST could also convert an HLS overlay into credit tags and graphics. This device would allow the programmer to feel comfortable deploying the edge devices knowing they are running the same software and creating the same feed, albeit at the appropriate codec/bitrate/audios for the affiliate/service group.

4.1.2. Federated Rights Management

Some affiliates will want to take the encoded and encrypted ABR files direct from the programmers origin. In order to manage this there would need to be a federated rights management system integrated into the programmer’s affiliate management system. Since most affiliates currently have a trusted relationship, and the IST is authorized to decrypt the content anyway, it could simply deliver the ABR segments to the affiliate to use for their IP delivery system, or to transcode with their own equipment.

Other affiliates, possibly in countries where there is no trusted relationship, would have a server that forwards DRM requests to the programmer to manage and have control of the encryption keys and tokens to the subscriber.

The programmers would likely store the content as CMAF files with a widely distributable encryption method. A key management system that can handle a wide variety of delivery scenarios will be needed. The programmer may need to directly authorize devices (similar to receivers) and the software edge device could be one such device. It could work with a key management server at the affiliate on a wholesale or retail model where it could grant the affiliate access to the keys, as most affiliates today typically are trusted with in-the-clear content in their headends. The affiliate would apply their own DRM and authentication before using the feed just as they do to their linear feeds today. The federated rights manager could also manage the DRM down to the individual edge device or even BYOD device DRM for some smaller affiliates.

Another use for this technique is to deliver network feeds to alternate locations such as international hotels that cannot put up a satellite dish. It should be simple for the distribution group to authorize these devices as an affiliate receiver.

4.1.3. Compression

With new AI and machine learning compression techniques, the ABR encode can save 10-40% bitrate at a higher quality using dynamic resolution, framerate and other encoding parameters. Dynamically changing resolution or framerate is not possible with a traditional transport stream, but if the receiver has transcode capabilities, these techniques can be used since the transcoder will decode the input and convert to a legal transport stream required by the legacy set top boxes. This would reduce the IP distribution costs with ABR content and a single transcode at the affiliate to restore the transport stream in the format needed, further reducing required bandwidth per affiliate and associated CDN costs. It would not be possible to use all of these methods on a pure transport stream over satellite, so the system is using more bandwidth then an IP segmented system would require. Each feed can be optimized individually instead of fitting it in to a statistical multiplex with only bitrate to manage.

4.1.4. Satellite vs IP

When comparing to satellite receivers, one needs to remember that,

1) Not all affiliates take all channels (HD, SD, East/West, Codec, and the channels package)
2) The channel lineup on any receiver/transponder is fixed
3) To get the appropriate channels to affiliates may require multiple receivers while only taking a few feeds off of each transponder.

When using CDN delivered segmented feeds, only the required video (codec, resolution) and audio feeds need to be delivered. It is conceivable with a switched digital affiliate architecture, feeds that are not being watched at the current time do not even need to be sent by the programmer, or pulled by the affiliate, allowing for a much wider range of channels to be optionally available without wasting ingest bandwidth. While a satellite infrastructure delivers all feeds to all locations, that is rarely needed with most of the larger programming networks. As an example, there are approximately 3000 affiliate receive sites in the US. This varies, of course, by programmer and network. A typical cost for a protected C band transponder is fixed, typically with a 5 year or longer contract, but much of that may be wasted on delivering networks that only a small subset of affiliates require. With the costs of C band relocation considered, the number of protected transponders to deliver all the networks to all locations, the total satellite cost is non-trivial. When sending a program over a CDN you can add or subtract bandwidth at any time, although that may affect the cost per GB.

Another satellite limitation is audio variants and associated bandwidth. For example, consider a programmer that needs to deliver an English 5.1 surround track, Spanish, French, descriptive video (possibly in multiple languages) and possibly a secondary audio programming (SAP) channel that varies from descriptive video to Spanish to English depending on what is available in the content. Some programmers that want to run addressable ads also need to send out two different Nielsen SIDs effectively doubling the audio content. This can consume 1.6 Mb or more bandwidth per channel. When running 10 AVC networks on a DVB-S2 transponder the 16 Mb out of 74 Mb is workable. When trying to run 20 HEVC networks on DVB-S2x the 32 Mb out of 94 Mb will definitely hurt video quality. On IP delivered content only the required Audio tracks need to be delivered.

When using a software edge device, audio can be managed by transcoding as well. A modern object audio format with personalization capabilities can be used, such as Dolby AC4 Atmos or MPEG-H. One lower bitrate object audio feed can be delivered and create the appropriate feeds the affiliate needs at the edge with the proper PAT/PMT structures the affiliate uses. The reader is referred to SCTE 248 if they would like to look into this topic further.

If a programmer has 6 transponders plus encoding, power, uplink, maintenance, personnel etc. the costs add up quickly. Typically, they will also have an ABR encode farm for TVE delivery. Since most transponders today are DVB-S2 running about 74 Mb/S and not DVB-S2X at maybe 94 Mb/S, each transponder typically carries 10 HD networks. DVB S2X would allow possibly 15 networks but would require an expensive receiver upgrade cycle. Going to a denser codec such as HEVC or VVC would require another receiver upgrade. If they used a software defined receiver for that upgrade, then future upgrade costs could be minimized and the transition to IP delivery could be started.

With 6 transponders, 10 networks per and 3000 receive sites a programmer could deliver 180,000 receive channels and if you compared that to CDN costs it would likely be close if they had a very good CDN price/GB/yr. But if you looked closely at what networks the affiliates actually took you would likely be in the 40,000 or less receive channels range, and the CDN would be 4-5x cheaper than satellite delivery. Or, if they did not have an economical CDN cost/GB, it would keep the costs similar, but they could retire the satellite infrastructure and have no long term contracts.

Programmers also need to use up transponder space for east and west coast feeds, especially if there are live events. Many programmers are reluctant to trust a receiver to implement the time delays for west coast feeds. With IP delivery, it is only necessary to send the appropriate timed manifest to the edge devices and could create many unique time zone feeds at minimal expense. If some satellite delivery was still being used for a very small affiliate, a west coast delay could be implemented at minimal risk until the affiliate could be moved to IP delivery.

The main point here is if you are going to have to do an upgrade for DVB S2X or codec, it is likely to be more cost effective to move to IP now, or at the very least, install a software defined receiver that can transition from satellite to IP in the future.

4.1.5. Production

Programmers have multiple options depending on
1) Live or pre-recorded content
2) Blackout requirements
3) Low latency requirements
4) Graphics overlays added during playout
5) Advertising and programming signaling and markers (SCTE 35)
6) Available metadata (SCTE 224)

The basic idea is that most content that can be pre-encoded ahead of time and stored on the programmer's origin. If this is all the programmer has, then a linear channel is made by creating a live manifest using the stored assets. VOD is also instantly available by creating the appropriate static manifests. Addressable ad insertion for the end user on a TVE playback or an affiliate ad zone on an IST can be done with manifest manipulation. This is by far the most cost-effective solution as it can eliminate expensive SDI or SMPTE 2110 broadcast chains.

Some networks could even create live manifest files from content sitting on their origin servers for their TVE or Go apps. This eliminates the broadcast chain and could save a significant amount of cost and complexity. It can also allow the programmer to spin up as many custom or niche networks it wants at almost no cost.

For live news or sports, the current infrastructure can feed real time ABR encoders with low latency if required. Using appropriate SCTE 35 markers and SCTE 224 metadata, the edge device can handle ad insertion and regional blackouts. These can also be managed with manifest manipulation where the programmer creates the correct manifest for each IST. A broadcast playout system could manage manifests between live events and stored content by creating the proper manifest as the live ABR content is also a simple sequence of files/fragments.

4.2. Affiliate

A small affiliate may only have one IST at their headend. Larger affiliates may want to add a second or more for system and geographic redundancy. Since this is a software only function, they can build virtual machines in a data center and use their network to get the outputs to the edge.

4.2.1. Acquisition

The affiliate will likely have multiple programmer delivery methods for some time to come. These may include,

1) Current satellite delivered feeds either taken directly or used with receiver transcoders.
2) Mezzanine feeds delivered over direct fiber or a distribution network, either compressed or uncompressed.
3) IP delivered using a reliable UDP protocol (SRT, RIST, proprietary)
4) IP delivered using a segmented protocol (HLS or DASH, preferably CMAF files)

For the legacy methods 1-3 affiliates can for a reasonable cost install ABR encoding and packaging to drive local/node edge devices to power legacy and over time move subscribers to IP devices either supplied by the operator or BYOD. With an appropriate federated rights management system they could directly use the segmented delivery content to IST or to IP set tops.

For programmers that move to a segmented IP delivery model the affiliate could either deploy (or the programmer could deploy) a single IST to act as a receiver and blackout controller. The affiliate could also drive the IST further into their network to manage ad insertion for their current zoned infrastructure or install more IST instances to create finer grained ad zones. With more IST instances deployed this is a win for the programmer as they are just supplying content and no longer have to supply a receiver/transcoder. The affiliate wins by having a lower cost DPI solution to get more ad revenue and eliminate their legacy transport stream plant.

The affiliate may also want to cache the segmented content for delivery to BYOD players. The rights management system should be able to handle the duration that assets can be kept in cache.

4.2.2. Advertising

For programmers that stay with the legacy transport stream delivery, it may be more cost effective for the affiliate to install a live transcoder/packager to allow the legacy ad splicer to be retired, and move to a full segmented IP distribution with ad insertion. This also allows the ad selection process to go from a legacy schedule to a dynamically inserted ad. The affiliate knows which households are watching the network in the service group(s) being fed from that IST and can select a better ad targeted to that group.

As the IST is at the affiliates edge, it can play out the appropriate codec for the service group. With switched digital video or finer service groups, that will be significantly more bandwidth efficient. It may also allow the programmer to replace a small number of older set tops to upgrade an entire service group to a denser codec and free up spectrum for other uses.

By deploying more IST instances for local ad insertion much closer to the edge at a lower cost/splice, the affiliate can get closer to full addressability, although that is not always needed. Since most television networks these days already segment the users into similar demographics, just by choosing to watch a certain program you are likely part of a target audience as shown in Figure 1. Even more likely is that if you live on the same node or smaller zone, you have a lot of demographics similar to your neighbors. For many advertisers that is more than enough addressability. One should also remember that with full addressability you can play any ad, there is always a much smaller set of ads that are currently in rotation and with reach and frequency issues, the selection set is usually quite small.

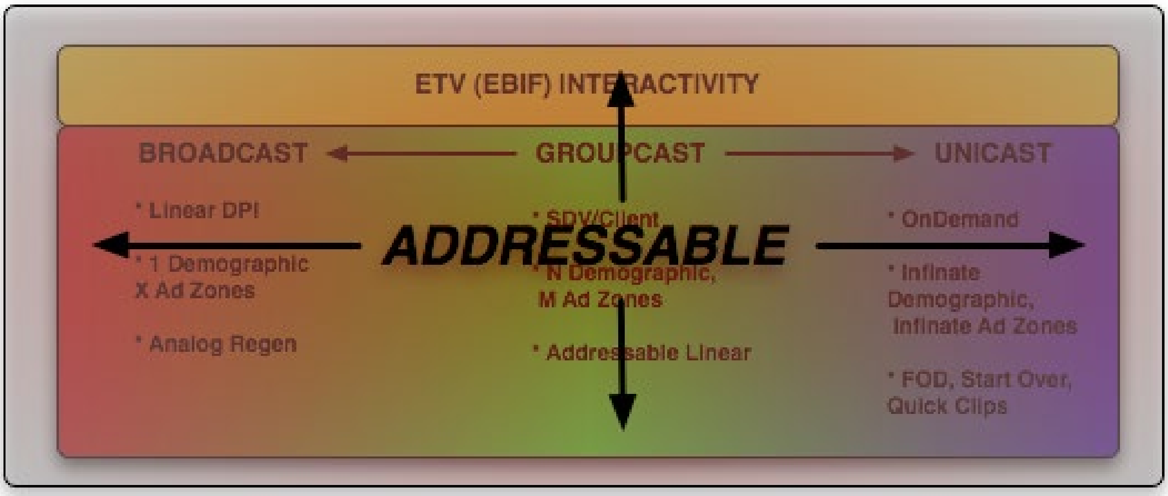

Figure 1 – Addressable advertisement spectrum

The next two Figures apply if the affiliate is using switched broadcast. While at peak viewing times the QAM bandwidth may be full but during most hours of the day there may be extra bandwidth that can be used to deliver a wider set of ads that map to the current viewers. Implementers could also consider spinning up an extra channel if you have some very high value ads (such as a car lease expiring) to a specific customer, or that customer may be the only person viewing that network in that zone. This can easily be accomplished with an IP to transport stream edge device with manifest manipulation.

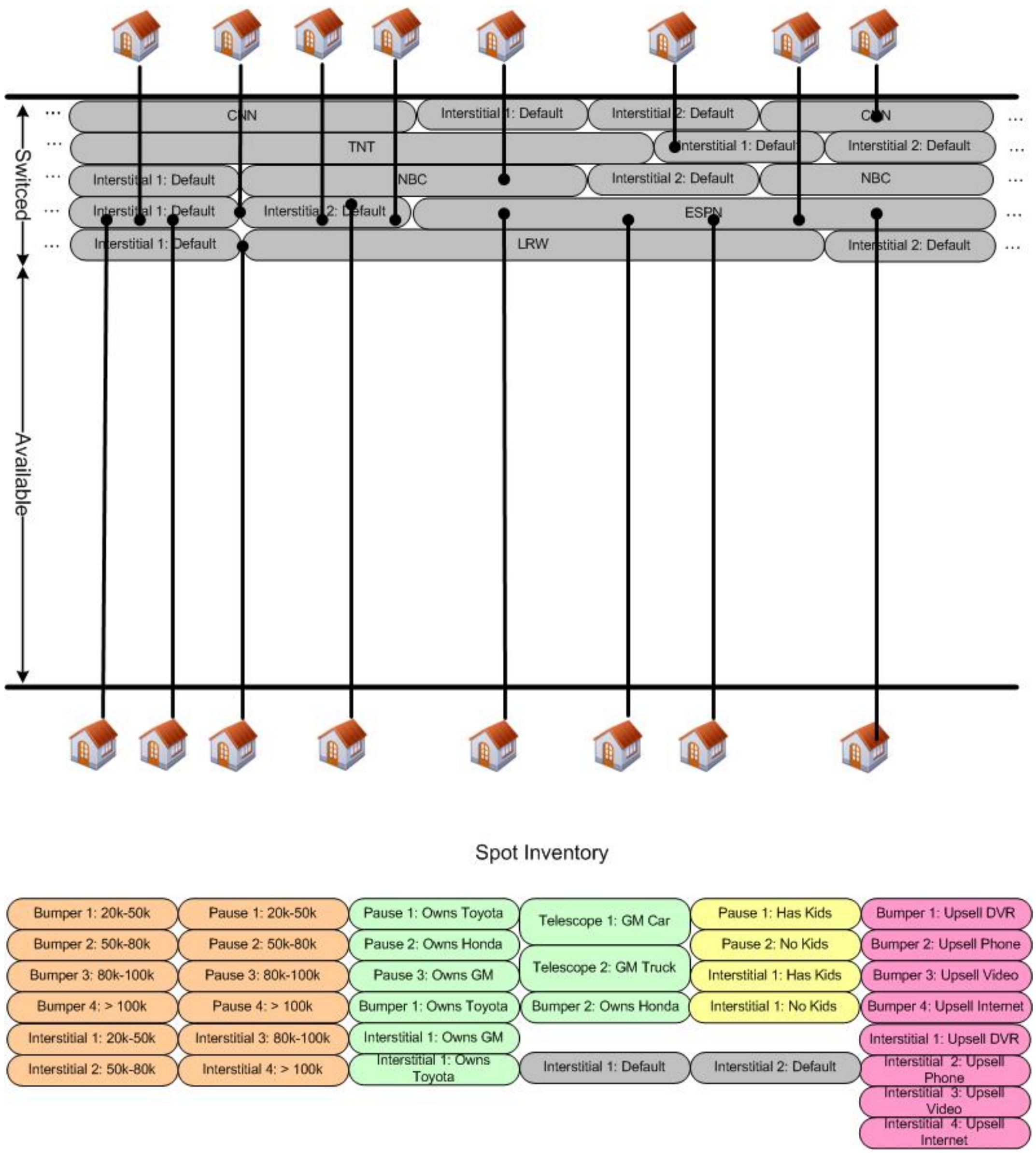

Figure 2 – Unused switched video spectrum

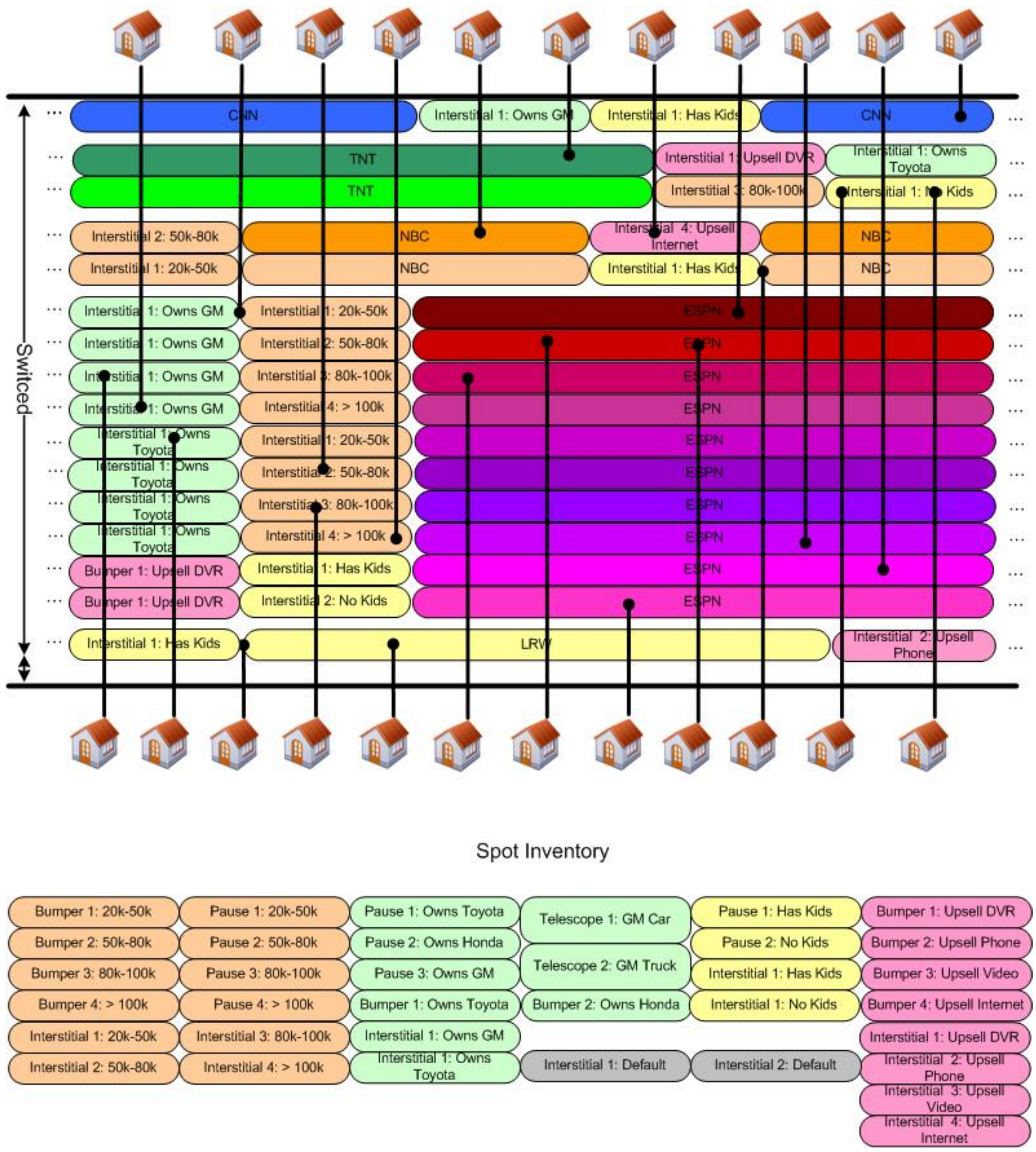

Figure 3 – Addressable switched video spectrum utiliized

Together

- Programmers can deliver content via origin/manifest
- MVPDs can deliver directly to IP set tops or edge devices where they can be ad inserted.

5. Implementation questions

Unfortunately, it is not easy to build a simple model for either programmers or affiliates. Programmers distribute to many affiliates with different needs and affiliates get programming from many programmers with different sources. In this section we try to cover many of the questions that need to be asked to build a model of the costs to move to IP distribution, the savings that can be had along with additional revenue sources.

5.1. Programmers

5.1.1. Questions

Current Planned networks and affiliates
1) How many networks do you have?
    a. East/west feeds
    b. Blackouts
    c. Variants (different ads for different countries, languages)
2) How many receive sites?
3) How many actual channels in each receive site total?
4) Special circumstances, (e.g. Cruise Ships, can they be moved to an aggregator)

What are current costs for
1) Satellite transponders, spare transponders, backups, in orbit or antenna rotate?
2) Legacy encode infrastructure (personnel, space, power, maintenance, disaster recovery)?
3) Receiver encryption management and authorization staff?
4) Uplink (personnel, power, regulatory, maintenance, disaster recovery)?
5) TVE / ABR encoding present or planned?
6) Federated rights management system?
7) CDN?
8) Any direct fiber, maintenance, CoLo bridging?

Production
1) For Stored playout, do programmers have the content already on the origin (for example most movie networks)? If so, then just create a live manifest.
2) How much network time is stored playout vs Live (News, Sports)?
3) New feeds for HDR, 4K, 8K, Special events, sports, how would you deliver these?
4) Are you moving to Cloud production (public/private/hybrid)?

5.1.2. Future considerations

5G auction and reduction in satellite spectrum, with likely increases in transponder cost. There may be a need to switch receivers to HEVC, AV1, VVC and DVB-S2X, and if so, is a full refresh required anyway?

Alternatively, options exist to transmit using a dense codec over IP, put a transcoder at the affiliate to transcode the chunks in to MPEG2, AVC, SD or whatever and cache locally. Will top 20 (90+% subscribers or so) be fiber, and for the remaining 2980 destinations would lower bitrate for say 720p HEVC be adequate? Significant CDN savings are available at some additional transcode expense.

Most large programmers as part of larger companies have better computer buying agreements and may want to provide the hardware and just purchase software.

5.1.3. Advertising

Is the Programmer doing Ad Insertion using server-side manifest manipulation? How many unique manifests are required? Geo zone? Data from affiliate or other source?

In order to give the affiliates more zones, would the programmer be interested in helping to fund a denser deployment if the affiliate would include better data and share the ad capabilities?

5.2. Affiliates

5.2.1. Questions

1) How many networks?
2) How fine do you want to segment (Current ad zones, finer, hubs)?
3) How can Switched Digital be leveraged?
4) What are the likely Programmer delivery methods?
5) Would centralized acquisition or remote standalone headends be appropriate. If decentralized, how many remote sites in total?
6) What would be the required Internet backhaul bandwidth?
7) If TVE IP delivered product in the field, is transcoding ABR packaging used?
8) What codecs do the set tops support?
9) Are the set tops IP ABR capable?
10) Cost to remove legacy set tops?
11) Federated right management controller installed?

6. Conclusions

While it can take some time to answer all of the questions to move away from a legacy transport stream infrastructure, we do think that with the

- current trajectory of CDN cost reduction
- satellite costs that are likely going up, assuming that bandwidth is available
- Moore’s Law applied to computing power price/performance
- Ongoing and associated reductions in power, cooling, support and maintenance costs
- New revenue sources from addressable advertising
- Moves to cloud production and distribution

moving to an all IP distribution method for both programmers and affiliates makes sense for both to start serious investigation today.

7. Abbreviations and Definitions

7.1. Abbreviations

ABR	Adaptive bitrate
AV1	AOMedia Video 1
CDN	Content distribution network
FRM	Federated rights management
HD	High definition
HDR	High dynamic range

HEVC	High efficiency video coding
IP	Internet protocol
IRD	Integrated receiver decrypter
IRT	Integrated receiver transcoder
IST	Integrated segmented transcoder
ISBE	International Society of Broadband Experts
MPEG	Moving pictures experts group
MVPD	Multichannel video programming distributors
OTT	Over the top
RIST	Reliable internet stream transport
SCTE	Society of Cable Telecommunications Engineers
SD	Standard definition
SRT	Secure reliable transport
TVE	TV Everywhere
VVC	Versatile video coding
WCG	Wide color gamut

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HOW CLOUD TECHNOLOGY IS CHANGING THE LIVE TRANSCODING LANDSCAPE
HOW CAN OTT SERVICES MATCH THE QUALITY OF BROADCAST
T. Fautier Proceedings SMPTE Annual Technical Conference & Exhibition 2019

Blockchain-as-a-Service Application in Digital TV

A Technical Paper prepared for SCTE•ISBE by

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Table of Contents

Title	Page Number
Table of Contents	62
1. Introduction	63
1.1. Low viewer participation on Interactive TV	63
1.2. Proposed Solution	63
1.3. Other Similar Initiatives	64
1.4. Features of Blockchain-as-a-Service (BaaS)	64
2. Scenarios / Use cases	65
2.1. Surveys and Voting	65
2.2. Trivia Questions and Wagering	65
2.3. Aggressive Sales Claims	65
2.4. Product Promotions and Advertising	65
3. Solution Architecture	66
3.1. Viewer Interaction	67
3.2. Sync Feature	67
3.3. Steps in the Sync Process	68
3.4. Unified Architecture	68
3.5. Network Latency Concerns	70
3.6. Process Flow Diagrams	70
3.7. Interconnected Blockchains	71
4. Comparison with Other Blockchains	72
5. Conclusion	72
6. Abbreviations and Definitions	73
7. References	73

List of Figures

Title	Page Number
Figure 1 - Technology Integration	64
Figure 2 - Synced Components	66
Figure 3 - User Interaction with Integrated Blockchain App	67
Figure 4 - Syncing TV Program with App Instance	68
Figure 5 - Unified Architecture	69
Figure 6 - Process Flow – User Interaction and Syncing	70
Figure 7 - Process Flow – Blockchain Layer Interaction	71
Figure 8 - Inter-connected Blockchain Network	72

List of Tables

Title	Page Number
Table 1 - Feature Comparison with Other Blockchains	72

1. Introduction

The gaming industry is abuzz after the recent Supreme Court decision to lift the Federal ban on sports betting [1]. This also has wide implications to *online* betting and gaming. One indicator of that is the race to secure IP rights [2]. Peer-to-peer online betting platforms are mushrooming [3], and cryptocurrency is playing a major role in this nascent industry.

A corollary of the High Court decision was alleviating the stigma associated with online gambling. This in turn has enabled novel betting products on TV [4]. In this paper we present a more innocuous, yet timely, application which could pave the way for new consumer products.

The problem being addressed is the low viewer participation on interactive digital video applications. Such applications would include game shows, consumer surveys, polling and wagering on TV. Viewers generally shy away from these product offers out of privacy concerns. Even when rewards are offered, consumers are not enthused due to the lack of a trustworthy payment system. A 'BaaS' solution is presented by integrating blockchain technology with digital media delivery networks.

1.1. Low viewer participation on Interactive TV

Low viewer participation can be attributed to customer concerns and the lack of a suitable technical solution.

- Privacy Concerns – Consumers are wary of sharing their personal information. There is renewed awareness in the wake of new privacy regulations (GDPR and CCPA).
- Security Concerns – While privacy is a personal choice, security concerns stem from the unsecure transaction framework. While security failures are technical in nature, the impact could be monetary, or worse, loss of confidential data.
- Lack of trust – If the consumers don't believe they get rewarded as promised, then they see no reason to participate. (e.g. "Call now! First ten callers will get a bonus gift"). The veracity of such claims are questionable and law enforcement is lax. The erosion of trust translates into lack of interest on the part of the consumer.
- Technical barriers – Traditional cable networks have monolithic architectures, thus integrating novel technologies such as blockchain is a major challenge. Even for IP based networks, a sync (synchronize) mechanism is not available to link digital TV stream with a mobile app.

1.2. Proposed Solution

The solution is based on the confluence of three disparate technologies, as shown in Figure 1.

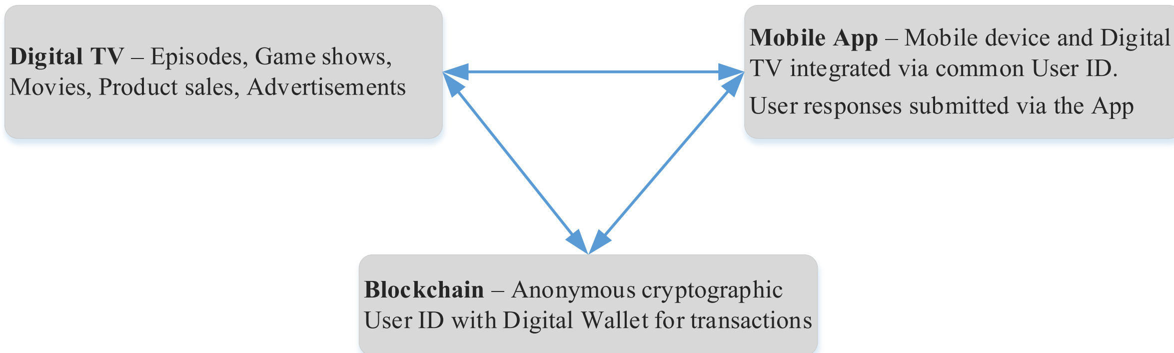

Figure 1 - Technology Integration

The three components of the solution are described below.

Digital TV – Unlike the traditional cable model, IP-based digital media delivery enables individual streams. In manifest manipulator based architecture, the media content is broken into segments and stored in the CDN origin server. The user client downloads video segments per the manifest. In this context, the content being referred to are TV episodes, game shows, movies, products sales promotions and advertisements. The proposed solution is applicable to other types of digital media delivery as well, such as ads on social media networks.

Mobile App – A trend among the young generation is watching TV while engaging with mobile apps such as Facebook [5], [6]. The proposed solution exploits this behavior to enhance viewer participation. A mobile app is inherently interactive and a convenient mode for user interaction with the digital TV program. Furthermore, an app on a second screen device (e.g. mobile phone), would not interfere with the primary viewing experience. The mobile device and the digital TV are integrated via common User-ID mapping, as described later. The mobile app is the mode through which users submit their responses.

Blockchain – The solution is targeted for enterprise based private blockchains. This is different from public blockchains which are decentralized, peer-to-peer networks with no central authority. A private blockchain does not require mining or a consensus mechanism. All transaction records are encrypted with asynchronous keys (public/private) to ensure privacy and security. Anonymity is thus a critical feature, as it would enable trustworthy interactions between parties who may or may not know each other. Since Blockchain transactions are not tied to fiat currency, fractional payments are possible (e.g. $ 0.001). The users need not disclose their identity. The cryptographic key usage would ensure consumer privacy.

1.3. Other Similar Initiatives

Blockchains, IPTV and mobile are three disjointed fields. As such integrated product initiatives are rare in the digital media delivery space. Existing products are generally aimed at preventing ad fraud in the delivery pipeline [7].

1.4. Features of Blockchain-as-a-Service (BaaS)

Blockchains exhibit seemingly contradictory attributes: Anonymity and Transparency. The former is achieved through PKE (Public Key Encryption) and is integral to the solution presented. Anonymity ensures trustworthy interactions between parties who may or may not know each other. The latter aspect (transparency) manifests due to the immutability of block creation process. The steps include creating Merkel trees, generating validated block hashes and forming blocks into an interconnected unalterable chain. Any change of block content would cause a noticeable change in the hash value, thus preserving transparency.

Smart Contracts are code snippets with conditions and actions listed. They run on top of the Blockchain network layer. In general implementations, smart contracts trigger payments once the conditions of a transaction are met. (The term *smart contract* was coined by Ethereum. The IBM Hyperledger blockchain refers to it as 'chaincode'). Blockchain based products safeguards consumer PII since all transaction records are encrypted.

BaaS model implies a hosted platform on which others build blockchain applications. However, that definition is restrictive and shall include blockchain-based novel product offerings as well.

2. Scenarios / Use cases

The unified architecture enables novel consumer products. Several applications are described below.

2.1. Surveys and Voting

Popular TV shows promote viewer engagement through voting (via texting/calling). Consumers are somewhat reluctant to participate out of privacy concerns. While anonymity is desired it also raises the question of authenticity. The integration with Service Provider network prevents rogue voting and assures authenticity. Encryption provides anonymity. Consumers who usually shun away from product/political surveys may find the disclosed solution allay their privacy concerns.

2.2. Trivia Questions and Wagering

In a typical scenario, TV viewers see trivia questions flash at the bottom of the screen and respond anonymously via the mobile app. Such queries may range from celebrity trivia, product purchases, user comments and wagering to 'whodunit' type questions about the program being watched. Viewers will be able to respond while concealing their identity. 'Digital wallets' in the blockchain furnish an anonymous payment system. To prevent a deluge of unwanted texts, the concept of 'Reputation Index' (similar to Yelp etc.) is introduced.

2.3. Aggressive Sales Claims

Consumers are not enthused about sales gimmicks such as, "*First 100 callers get an extra discount*", for two reasons. First is the privacy concern associated with divulging personal data. Secondly, the veracity of such claims are dubious as they are hard to prove. In the proposed solution, the privacy concern is addressed via public/private key architecture as noted above. The veracity issue is addressed via 'smart contracts', which automatically trigger payments once the conditions are met.

2.4. Product Promotions and Advertising

An Advertiser may decide to pay viewers $0.001 for watching a new Ad. (Note – Ad viewability can be measured with percentile beacons, which are electronic signals emanated when a portion of the ad is aired. For instance, when three-fourths of an ad is viewed, it will trigger the 75th percentile beacon). Consumers will be able to participate anonymously, and payments will be made to their digital wallets. Any concerns about bots (masquerading as real customers), would be allayed because the calls can only be originated from Service Provider authorized gateways. Unlike in a public blockchain, the network owner has full control of the private blockchain.

3. Solution Architecture

While blockchain enables a secure payment mode, that alone is not sufficient to support the scenarios described. A modified architecture suitable for IP based digital media delivery is presented below.

In a typical scenario, a TV viewer watches a program while having the mobile phone on the side. If interactivity is desired the user may turn on the mobile app which is synced to the program being watched. The app has a dual role: It interfaces with digital media stream (IPTV) and synchronized to the program content. As a blockchain based app with transactional capability, it acts as a digital wallet. This blockchain is a private and permissioned one (not a public blockchain). The digital wallets are located in the multitude of user mobile devices.

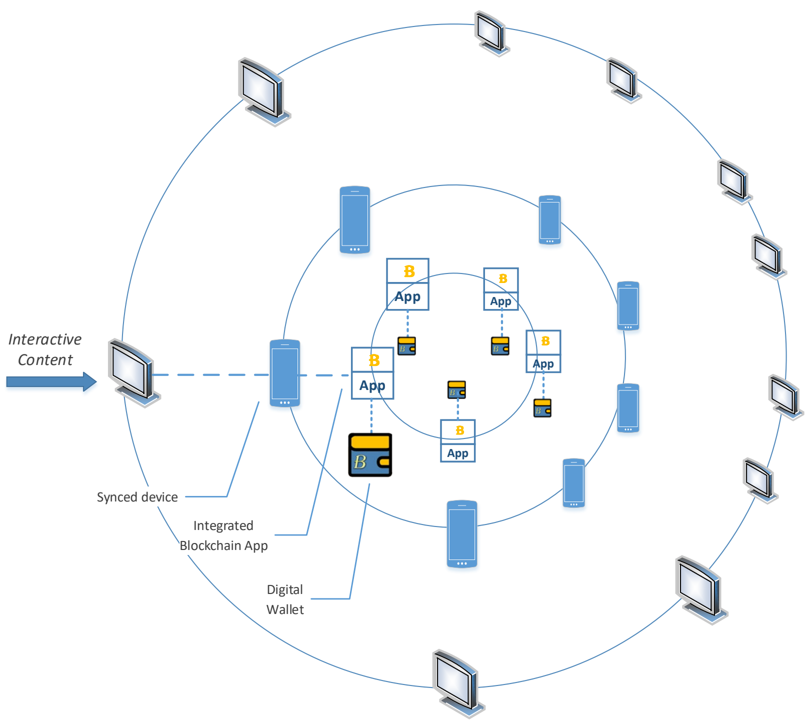

Figure 2 - Synced Components

Figure 2 illustrates a network of digital media receivers attached to a content distributor network. The users also have the ancillary devices synced to the current program being aired. Note that 'syncing' is not duplicating the TV stream, but displaying the associated content for each stream. (See section 3.2 for details). The blockchain app provides secure interactions between user devices.

The synced components are as follows.

- Digital Media receiver (Smart TV/ Roku, Apple TV…)
- Ancillary device – Mobile/tablet device *synced* to the same service provider network

- Integrated blockchain App with Digital Wallet for transactions

3.1. Viewer Interaction

Figure 3 depicts the wagering use case, by way of example. The mode of operation is peer-to-peer.

In this scenario, the TV viewer wishes to submit a question (or place a wager) to other viewers. Once the mobile phone app is turned on, it synchronizes with the TV program being watched and the viewer is able to interact with other participants. Other viewers also respond anonymously. The official answer to the question is stored in an external authoritative server (*Oracle* in blockchain terminology).

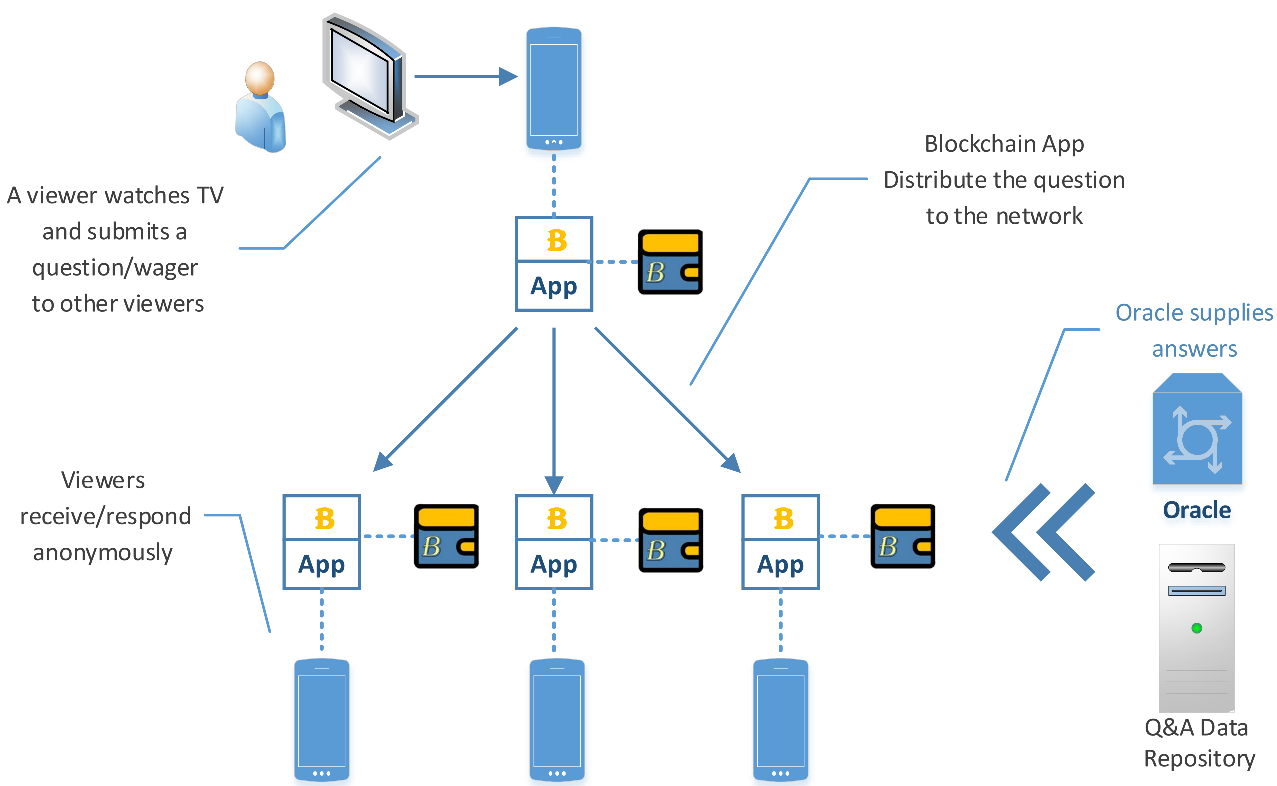

Figure 3 - User Interaction with Integrated Blockchain App

3.2. Sync Feature

The 'sync' feature is an integral part of the solution. Note that 'syncing' in this context does not mean duplicating the TV feed. Instead, the ancillary device (mobile/tablet) will display the 'synced content' (e.g. polls, surveys and opinions), applicable for the specific program. For example, in Figure 4, the TV is tuned to channel/program #123. The mobile app displays the associated synced content for that particular program (in this case a trivia question). The primary and supplemental content are synced when the 'sync button' on the App is selected.

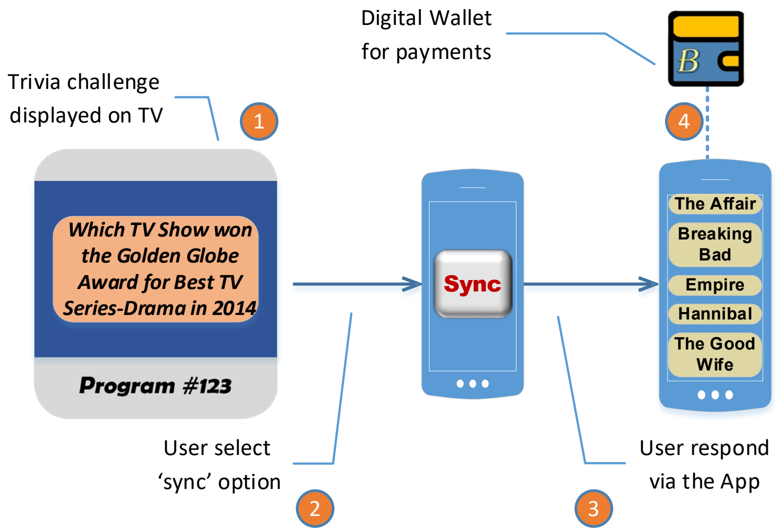

Figure 4 - Syncing TV Program with App Instance

3.3. Steps in the Sync Process

1. (Figure 4) – A user is watching program #123 on a digital display device. The trivia question is displayed at the bottom of the screen (or on a separate device, social network app, separate browser window etc.).
2. User presses 'sync' button in the mobile device/tablet app. The device makes contact with the sync Server.
3. The user is presented with 'synced content' on the second screen. User inputs her response on the screen.
4. The response is transmitted to the outside entity which created the quiz. The answers/responses are compared with the Oracle database. Any payments/wins will be delivered to the digital wallet.

3.4. Unified Architecture

Figure 5 refers to an adaptive bit rate (ABR) based streaming instance. In a typical streaming scenario, the broadcasted TV/media content stream from Programmer is received by the content distributor (also known as service provider or network operator). The Encoder/Transcoder performs format changes. The Packager/Segmenter splices the media content into chunks. The video/audio segments, along with an index file (manifest) for segment identification, are placed for storage on a CDN Origin server. The Manifest Manipulator modifies the manifest to accommodate the Ad segments. During playback time, a customer device would pull media segments (chunks) from the Origin server per the order listed in the manifest/index file. An example of a customer device in this context would be a set-top-box client. Application of blockchain technology to ABR streaming is discussed in [8].

Program content and the synced content (also called secondary / supplemental content), are stored on the network operator CDN. The sync server facilitates syncing between program content and the mobile app. The blockchain depicted in Figure 5 is for a single domain within a service provider network. (See Section 3.6 on extending the model to multiple domains). The blockchain server ensures correct debiting of crypto currencies to individual wallets/accounts. The gateway server role is to perform any remapping as needed to communicate with external entities. Remapping is the encapsulation of native blockchain data inside an IP packet for transmission.

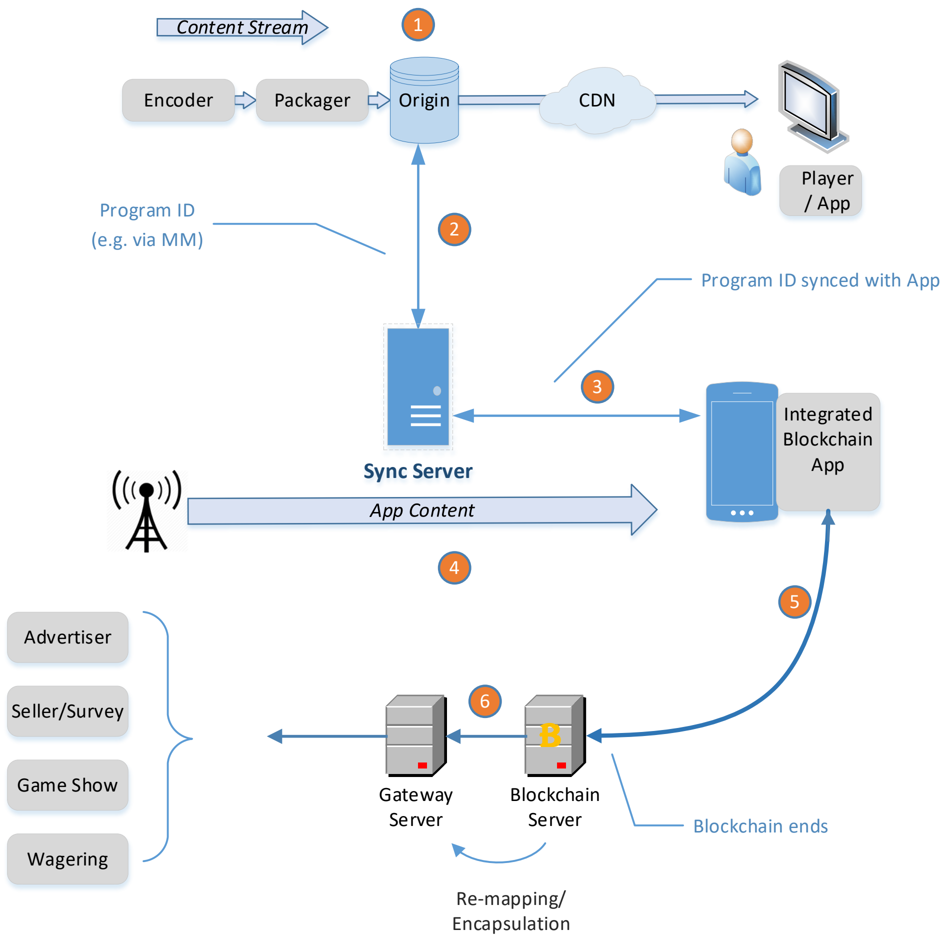

Figure 5 - Unified Architecture

Process Steps:
1) TV content is delivered to the user device. Assume the end-user is watching TV and also invokes Mobile App.
2) The user selects ‘sync’ option on the mobile. Sync server correlates* current program’s ID for syncing.
3) Sync server supplies currently tuned program ID to the mobile app to retrieve corresponding content.
4) Mobile app retrieves synced content.
5) Mobile app and blockchain based digital wallet are engaged for user interaction.
6) Blockchain server is the end-point of the intra-network. Communication with external entities is via a gateway server using cryptographic public keys as addresses/identifiers.

*The correlation here refers to identifying the mobile device associated with the end-user device, (this can be done using MAC address data obtained during the App set-up or registration phase). The sync server provides the ID of the program currently on air, which is then used by the mobile app to download the synced content from the secondary content database server. In effect, the current program ID maps/correlates to the secondary content.

3.5. Network Latency Concerns

Transmission and processing delays across heterogeneous networks can vary significantly. Latency issues in cellular networks are well-known and could unfairly impact some viewers if their responses are delayed. This issue could be mitigated by accommodating the end point timestamp difference, and then adding a time lag to the sync-server response as applicable. The delay issue is prevalent in current implementations of interactive TV games as well. The impact is perhaps less severe for BaaS applications, due to homogeneity in network characteristics in a single service provider network.

3.6. Process Flow Diagrams

Figure 6 contains the sequence of steps from the viewer engagement through the syncing process. Figure 7 depicts the secure blockchain layer interaction.

In Figure 6, metadata are the information needed to perform sync function, such as current program ID, channel ID or time stamp. Such data are supplied to the 'sync server' (e.g. via manifest manipulator), and stored in its database. During pre-registration process (done prior), the sync server ties the mobile App to the matching end-user home device. This mapping is based on the MAC address of each device during App set up/registration phase.

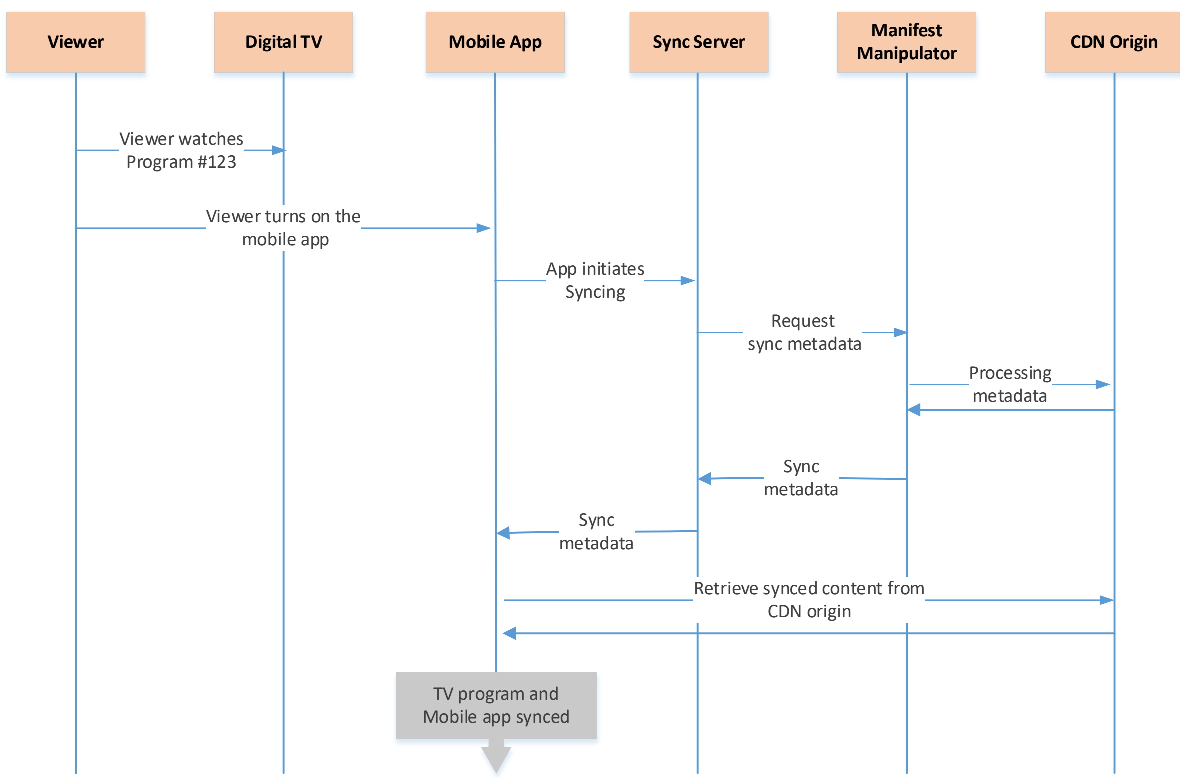

Figure 6 - Process Flow – User Interaction and Syncing

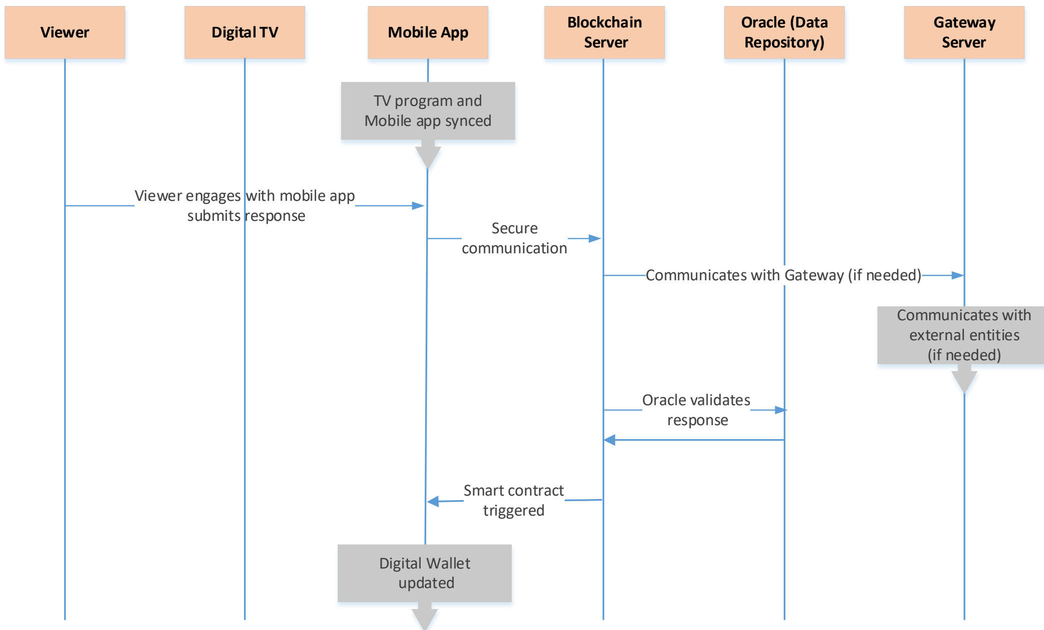

Figure 7 - Process Flow – Blockchain Layer Interaction

3.7. Interconnected Blockchains

The blockchain instance presented earlier is internal to the enterprise (i.e. behind the firewall). Alternately the blockchain can be virtually extended to multiple enterprises. Such an arrangement is known as a federated or consortium blockchain. The multiple blockchain domains are physically disparate but connected via VPN tunnels. Any communication with the outside world is via the "Gateway server', whose role is to encapsulate the blockchain data. Encapsulation or 'tunneling' is common in packet networking and is usually done by adding an IP V4/V6 header. When an encapsulated IP packet (e.g. from Advertiser network) is received by the Gateway server, the IP header is stripped and the blockchain data is passed on to the Blockchain server for processing.

IP Gateway servers are entry/exit points to each network domain. The gateway server can also incorporate blockchain functionality as shown in Figure 8. In this instance, the blockchain is extended seamlessly via VPN.

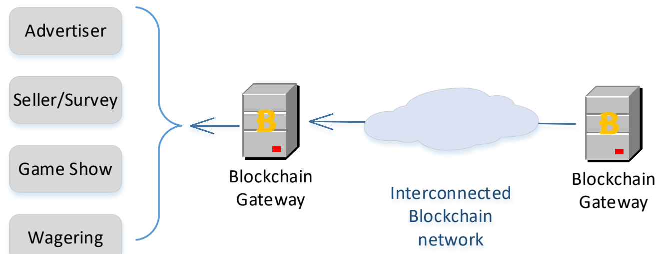

Figure 8 - Inter-connected Blockchain Network

4. Comparison with Other Blockchains

Blockchain architecture varies by implementation and it is hard to define a standard model. For example, once the 2nd largest cryptocurrency, Ripple is devoid of the salient 'distributed ledger' feature of blockchain. Oracle and Smart Contract concepts were introduced by Ethereum and were not part of original Bitcoin protocol. Also, unlike Bitcoin, most private blockchains don't have group consensus mechanism (mining). And some even advocate centralized control. Table 1 illustrates this difference by comparing primary features of present solution against other implementations.

Table 1 - Feature Comparison with Other Blockchains

Feature	Other Blockchains	Proposed	Comments
Blockchain type	Mostly Public	Private	e.g. Ethereum, Bitcoin
Cryptographic hashing	Y	Y	
Transactions	Buying/Selling	Payments	
Block Mining	Y	N/A	(see comment below)
Smart contracts	Y	Y	
Block formation	Y	N	
Consensus Mechanism	Byzantine Fault Tolerance	N/A	(see comment below)

As the proposed solution is a private blockchain with full control by the network administrator, the concept of 'data mining' (or the usage of 'Nonce' to adjust the difficulty), is not relevant. Technically it falls under POS (proof-of-stake), with one party (Network Operator) governing the decision-making process. Any manifestation of Byzantine faults will be resolved by the network Administrator.

Forming blocks and creating the chain are optional for the proposed architecture. Since the blockchain would be private and not public, block formation is not an essential requirement. However, block formation is still good business practice from a record-keeping point of view.

5. Conclusion

An implementable Blockchain-as-a-service (BaaS) solution is presented. Cable TV companies are facing stiff competition from new entrants to the field as customers are lured away by new low-cost streaming products. Hence, offering a novel service would be a new revenue opportunity.

6. Abbreviations and Definitions

ABR	Adaptive Bit Rate
BaaS	Blockchain-as-a-service
CCPA	California Consumer Privacy Act
CDN	Content Delivery Network
GDPR	General Data Protection Regulation
MM	Manifest Manipulator
PII	Personally Identifiable Information
VPN	Virtual Private Network

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Diagnosing Visual Quality Impairments in High-Dynamic-Range/Wide-Color-Gamut Videos

A Technical Paper prepared for SCTE•ISBE by

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Table of Contents

Title **Page Number**

Table of Contents 75
1. Introduction 76
2. Quality Issues in HDR/WCG Videos 76
3. Diagnosing Visual Quality Impairments 78
4. Conclusions 82
5. Bibliography and References 82

List of Figures

Title **Page Number**

Figure 1 - An example of a practical workflow to generate a mezzanine file. 77

Figure 2 - Video frame (left) with banding artifacts, and banding map (right) created by an objective banding detection algorithm. 79

Figure 3 - Video frame (left) with strong blocking artifacts, and quality map (right) created by an objective video quality metric. 79

Figure 4 - Frames from the source (left) and degraded test (right) videos, and the color deviation map (bottom) created by an objective metric. 80

Figure 5 - Example of tone-mapping artifacts and the structural fidelity map created by an objective video quality metric. 81

1. Introduction

Content producers have been making great progress in the past few years adopting advanced technologies to create video content of ultra-high definition (UHD), high dynamic range (HDR), and wide color gamut (WCG). Meanwhile, there has been an accelerated growth of UHD/HDR/WCG content being delivered to consumers' home TVs and mobile devices. While consumers are enjoying the improved resolution/contrast/brightness/bit depth and enhanced richness of colors, maintaining the quality in video production and distribution becomes an ever greater challenge that content producers and cable, satellite, IPTV and OTT video distribution service providers have to face. The challenge arises not only because of the much larger bandwidth that is required to guarantee seamless UHD/HDR/WCG video transmission, but also because of the difficulty in preserving the visual quality during video production, post-production and delivery, and in maintaining consistent presentation over a wide variety of display devices at the studios and at the user ends.

It is important to note that HDR/WCG video content is much more prone to quality issues than Standard Dynamic Range (SDR) content of smaller color gamut, not only because of the higher user expectations, but also because any loss of texture/highlight/shadow details, any shifts of exposures, colors and skin tones, and any artifacts of blocking and banding, could be much more manifest on HDR/WCG displays and visual settings. Moreover, the perceptual visibility of such artifacts could vary depending on the display devices and settings. Taking banding, an annoying artifact frequently occurring in HDR/WCG content, as an example, its visibility could vary drastically across scenes and across viewing devices. To detect banding, a good understanding about the human visual system, the content attributes, the display characteristics, and the interplay between them is crucial. To remove or reduce banding, the video scenes and their associated metadata need to be processed, encoded and decoded in a consistent manner throughout the video production and distribution workflows.

Here we discuss the common quality issues in HDR/WCG video production and distribution. We will then discuss how such quality issues may be diagnosed through an end-to-end quality control framework, for which the most critical technology is an objective quality assessment method that can help identify, localize and assess the visual quality impairments in HDR/WCG videos.

2. Quality Issues in HDR/WCG Videos

HDR/WCG video distribution should aim for preserving the creative intent of content producers. Ideally, the video quality at any point along the video delivery chain should be compared against the pristine video graded by the artists, colorists and directors of photography at the grading suites. The journey of the source HDR/WCG videos from the grading suites to end users' viewing devices consists of multiple sophisticated stages, and quality issues may arise in any of these stages. A brief summary of the key stages is discussed below.

Mezzanine preparation. Immediately after color grading, motion pictures often go through the process of generating mezzanine files. Figure 1 demonstrates a typical workflow in studios in mezzanine file generation. Once grading content is done, an Output Display Transform (ODT) defined for a target delivery platform is applied to encode linear RGB using perceptual quantization (PQ) Opto-Electrical Transfer

Function (OETF) [1]. The output of this stage is PQ encoded RGB or equivalently R'G'B' in 16bits TIFF format. Assuming P3 color gamut [2] is used for grading and a theatrical ODT is used, there is a need for converting P3 color gamut to Rec. 2020 [3], which is the container of HDR videos in the distribution pipeline. Eventually, an intra frame coding is used to quantize and compress HDR frames. If the codec does not support R'G'B' color space like Apple ProRes, there is also a color space conversion involved in the process. Almost all such transformations are lossy and could potentially create visual quality impairment.

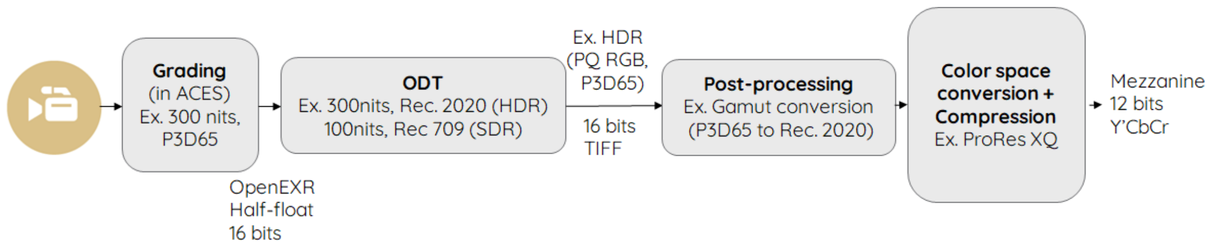

Figure 1 - An example of a practical workflow to generate a mezzanine file.

Transcoding and transmission. HDR Mezzanine files are often of high bitrate that cannot fit into the pipeline of subsequent video delivery chains. Therefore, transcoders such as HEVC, together with bit-depth mapping (often from 12 bits to 10 bits) and chroma subsampling, are typically used to further compress mezzanine files, leading to even stronger visual artifacts.

Display on user devices. With the advent of HDR filming techniques, display manufacturers sought to support HDR EOTFs and roll out displays that are capable of producing luminance above 100nits. Displays play an important role in the rendition of HDR videos. Consumer TVs and other viewing devices have huge variations in terms of hardware and software design, which is in addition to the largely varying physical limitations on the display technologies being used. As a result, the same HDR video stream may have significantly different visual appearances on different displays under different display modes, often creating dramatic deviation from what the content producers see at studios on calibrated professional displays.

HDR formats. A variety of HDR formats/standards have been used in practice for delivering HDR content, among which the common ones include HDR10 [1], HLG [4], Dolby Vision [5] and HDR 10+ [6]. These standards differ in the EOTF transfer function (e.g., PQ vs. Hybrid Log-Gamma), allowed bit depths (10 bits vs 12 bits), metadata formats (static vs. dynamic), and color representations. All of these variations are entangled with the variations in color grading platform, mezzanine file generation, transcoding technology, and display design, creating significant variations in the appearance of HDR content.

Eventually, human eyes are the ultimate consumers and the final judges of the visual quality of HDR/WCG videos. The most common visual quality impairments include:

- *Texture detail loss* is often caused by compression and bit depth reduction. In addition, HDR displays that cannot accommodate content peak brightness, often apply tone mapping techniques to reduce the dynamic range of the HDR content, leading to texture detail loss.

- *Blocking* is often produced by quantization in heavy compression, where artificial blocky structures may be produced and their visibility varies depending on the underlying texture content near the blocky regions.

- *Banding* is a common artifact that often appears in large regions of low textures and slow gradients, where large smooth regions are divided into flat bands with long and visually strong fake contours separating them. One complication in banding is that its visual appearance may vary not only depending on the bit-depth quantization and compression, but also on the noise level, the denoising effect of compression, and the HDR formats and displays.

- *Highlight and shadow detail loss* refers to the reduction of visibility of fine details in the brightest and darkest regions. They may be caused by any mismatch between the maximum/minimum content brightness, the OETF and EOTF functions, the bit-depth mapping algorithm, the maximum/minimum brightness of the display, and the physical limitation of the display technology. Highlight and shadow detail loss is critically important because the purpose of HDR technology is to improve the capability to expand the scene dynamic range, such that fine details in bright and dark regions that are invisible in SDR are clearly discerned.

- *Color distortion and skin tone deviation*. Color gamut mapping, color space conversion, chroma subsampling/upsampling, mismatching OETF and EOTF transformations, and compression may all contribute to color distortions, for which skin tone deviation is often the most noticeable.

- *Tone mapping artifacts*. In video distribution practice, we often encounter a mismatch between the higher dynamic range of video content (e.g., 10bits or 12bits HDR) and the lower dynamic range capability of displays (e.g., 8bits SDR), tone mapping has to be applied for bit-depth conversion, which is a source of severe quality degradations. Visually, such degradations may appear to be a combination of the loss of structural details, the loss of naturalness, and the loss of temporal consistency and smoothness.

3. Diagnosing Visual Quality Impairments

HDR/WCG video is prone to quality degradations throughout the video delivery chain. The most effective approach for quality control is to monitor it using an end-to-end framework [7], where quality testing probes are deployed at all transition points in the delivery chain, so that any quality deterioration can be captured and localized in a timely manner. The most important technology to enable such an end-to-end quality control system is an objective video quality assessment (VQA) metric that faithfully reflects the perceptual video quality. Such objective metrics need to be validated through comparisons with subjective testing on dedicated HDR/WCG video databases [8]. Unfortunately, conventional SDR VQA metrics, such as PSNR, SSIM [9], VQM [10] and VMAF [11], do not produce accurate assessment of HDR/WCG videos. This has inspired significant effort in the past years to overcome the challenge, represented by advancements over the SSIM method like SSIMPLUS [12], [13]. Meanwhile, the VMAF project has also been continuously making progress along this direction [14]. Here we show how some of the most significant visual impairments in HDR/WCG videos may be diagnosed.

Banding significantly degrades the visual Quality of Experience (QoE) of end users. Banding effect is particularly annoying as it frequently exhibits even in high definition, high bitrate HDR/WCG content, which otherwise appears to have nearly perfect quality. What often frustrates many practitioners is that simply increasing bit-depth and bitrate of a video does not necessarily lead to removal or reduction of banding. Figure 2 (left) gives an example of a video frame with severe banding artifacts in the background region. Two substantially different types of approaches have shown notable success at detecting banding.

The first approach is based learning deep neural network (DNN) predictors from large-scale datasets [15], where convolutional neural networks (CNNs) are trained in an end-to-end manner to classify local image patches into having or not having banding, and the local predictions are then aggregated to produce a global banding estimation of an image or video frame. The approach has been tested to be highly accurate when trained on large-scale databases, though the banding diagnosis does not go deep into pixel level. In addition, such a purely learning based approach does not offer much meaningful insight about why and how banding is happening, insight that may help correct or reduce banding. The second type of approach is based on detecting abrupt local activities in smooth image regions, and then analyzing the visibility of such activities from the perspectives of human visual system characteristics, display modes and properties, OETF and EOTF transfer features, color features, and viewing environment. Pixels that correspond to abrupt activities deemed visible as banding are then marked, which collectively constitute a banding map of the image or video frame. An example of such a banding map is shown in Fig. 2 (right), where the banding artifacts are highlighted by the white pixels. It appears that this knowledge-driven approach (as opposed to the learning-based DNN approach) not only detects banding, but also precisely localizes the banding impairment at pixel-precision.

Figure 2 - Video frame (left) with banding artifacts, and banding map (right) created by an objective banding detection algorithm.

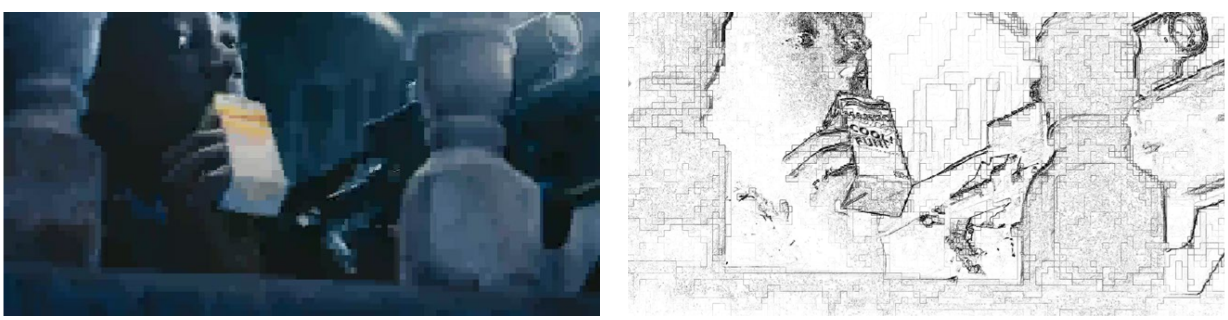

Figure 3 - Video frame (left) with strong blocking artifacts, and quality map (right) created by an objective video quality metric.

Blocking is mainly caused by block-based video compression, which is a common technology adopted in a majority of video coding standards used in practice. Unlike banding, blocking may occur in both smooth and texture regions of an image, as exemplified in Figure 3 (left). Blocking may be diagnosed by either blind (or no-reference) or non-blind (or full-reference) video quality metrics – the former detect blocking artifacts without referencing to the distortion-free original video, while the latter uses the original video as a reference. Successful blind blocking effect detection methods often quantify the magnitude of block edges based on human visual system features such as the texture masking effect [16]. In general, blind blocking detection methods are more convenient to deploy in practical systems, but less accurate, as image content may contain blocky features too. Non-blind or full-reference video quality metrics, especially those that measure the local structural similarities [9] [12] between the reference and test images, may be able to detect blocking effects in their quality maps. An example of such a quality map is given in Fig. 3 (right), where darker pixels indicate stronger visual artifacts. It can be observed that the blocking artifacts created by block-based hybrid video compression schemes are well detected and precisely localized on the quality map.

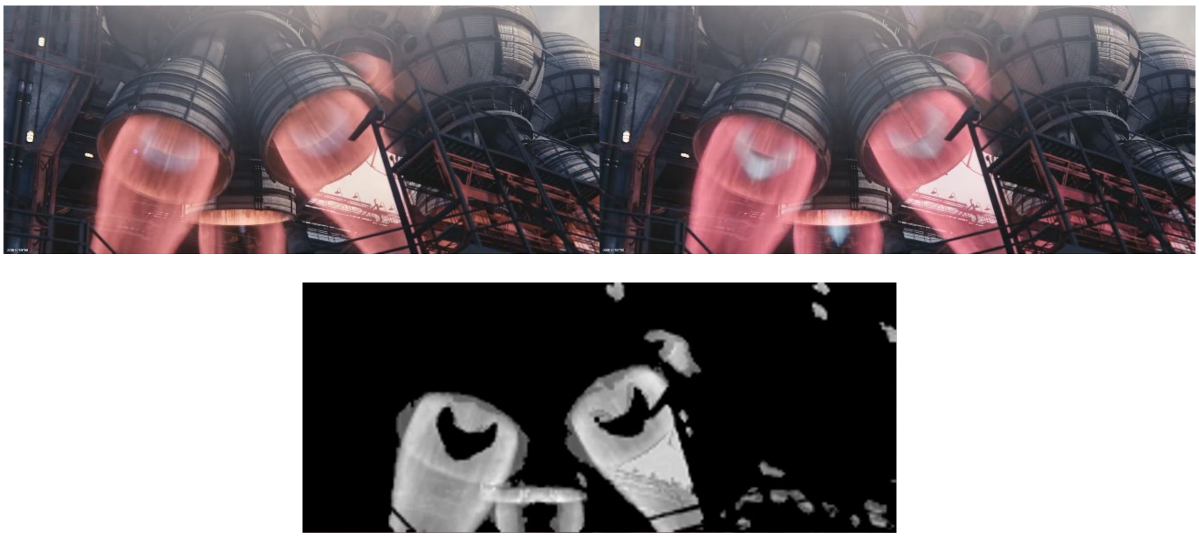

Figure 4 - Frames from the source (left) and degraded test (right) videos, and the color deviation map (bottom) created by an objective metric.

Due to the sophisticated video production and distribution workflows where color changes are often non-invertible (e.g., in color gamut mapping, color space conversion, chroma subsampling/upsampling, OETF and EOTF transformations, bit-depth conversion, and compression) and the studio professional displays and consumer viewing devices are largely mismatched, reproducing the exact colors seen at grading suites on common consumers' viewing devices is deemed impossible. However, there is a large playground on how to reduce the color deviations, for which the first step is to assess the color disparity in a perceptual meaningful way. One common approach towards this goal is to develop a perceptually uniform color space, within which ideally the same level of numerical change leads to the same level of visual difference and such uniformity should hold across the whole color space. It should be noted that none of the color representations used for creation/exchange of mezzanine files or transmission of compressed video streams, e.g., PQ-encoded R'B'G' or YCbCr, were derived for perceptual color uniformity. There has been a hundred-year effort of designing color spaces of perceptual uniformity [17] [18]. Some recent study suggests that great progress has been achieved over the years but there is still significant space for improvement [19]. Figure 4 compares two sample video frames, one from the source and the other from the test (degraded) videos, together with the color deviation map created by an objective video quality metric, where brighter regions signal higher levels of color deviations. Such color deviation maps play an important role in identifying and assessing how color/skin tone information is preserved during video distribution.

HDR to SDR tone mapping often produces complicated quality issues that have to be captured/described in multiple dimensions in terms of the loss of structural fidelity, the loss of naturalness, and the loss of temporal consistency and smoothness, with interactions between them. Specifically, to avoid fine structural details being washed out via bit-depth reduction, tone mapping operators strive to preserve the structural details, but the process often produces unnatural looking textures and colors. It is important for a video quality metric to be able to capture unnatural appearance of tone-mapped images. A joint consideration of both of the structural fidelity and statistical naturalness factors leads to the tone-mapped image quality index (TMQI) [20], which has been widely used in both industry and academic research for assessing the performance of tone mapping operators, and has also been successfully used to drive the optimal design and optimal fusion of tone mapping operators [21]. Figure 5 depicts two examples of visual artifacts generated through HDR to SDR tone-mapping. The left column shows images created from different tone-mapping parameters, and the right column is the corresponding visual distortion map, where darker regions indicate more significant information loss. When tone mapping operators are applied to videos, cross-frame consistency becomes a critical factor. Inconsistent inter-frame tone mapping often creates severe flickering across frames and unnatural luminance change across scenes. Thus a joint consideration of spatial ante temporal artifacts is desirable in objective video quality metrics [22].

Figure 5 - Example of tone-mapping artifacts and the structural fidelity map created by an objective video quality metric.

As HDR/WCG video becomes increasingly more popular, new artifacts will emerge that will pose new challenges to the HDR/WCG VQA metric. Continuous efforts need to be spent on studying the impact of the new artifacts and developing updated objective VQA algorithms to capture those impacts.

4. Conclusions

As the HDR/WCG video promises unprecedented viewer experience to consumers, quality control becomes crucial to ensure such promises deliver. Nevertheless, quality control of HDR/WCG content production and distribution is challenging, much more so as compared to delivering video content of SDR and smaller color gamut. Here we discuss the reasons that cause visual quality impairments in the production and distribution workflows of HDR/WCG videos, and lay out the common visual quality artifacts. We have also discussed the end-to-end quality control framework and the recent effort at developing dedicated objective video quality metrics that are effective at diagnosing the visual quality impairments in HDR/WCG videos. These methods and discussions pave the ways for the development of reliable quality control and quality optimization systems for HDR/WCG video production and distribution.

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