Maintaining High Quality of Experience in an Adaptive Bitrate System

WHITE PAPER

Broadcast TV has set a very high bar for viewer expectations and delivering a great quality of experience (QoE). As the trend and demand for multiscreen viewing and TV Everywhere or Over-The-Top (OTT) continues to grow, so does the demand for a high quality of experience with the best content on any device and at any time. Behind that multiscreen experience lies some very complex adaptive bit rate (ABR) technology and a new set of monitoring challenges.

Tektronix®

Contents

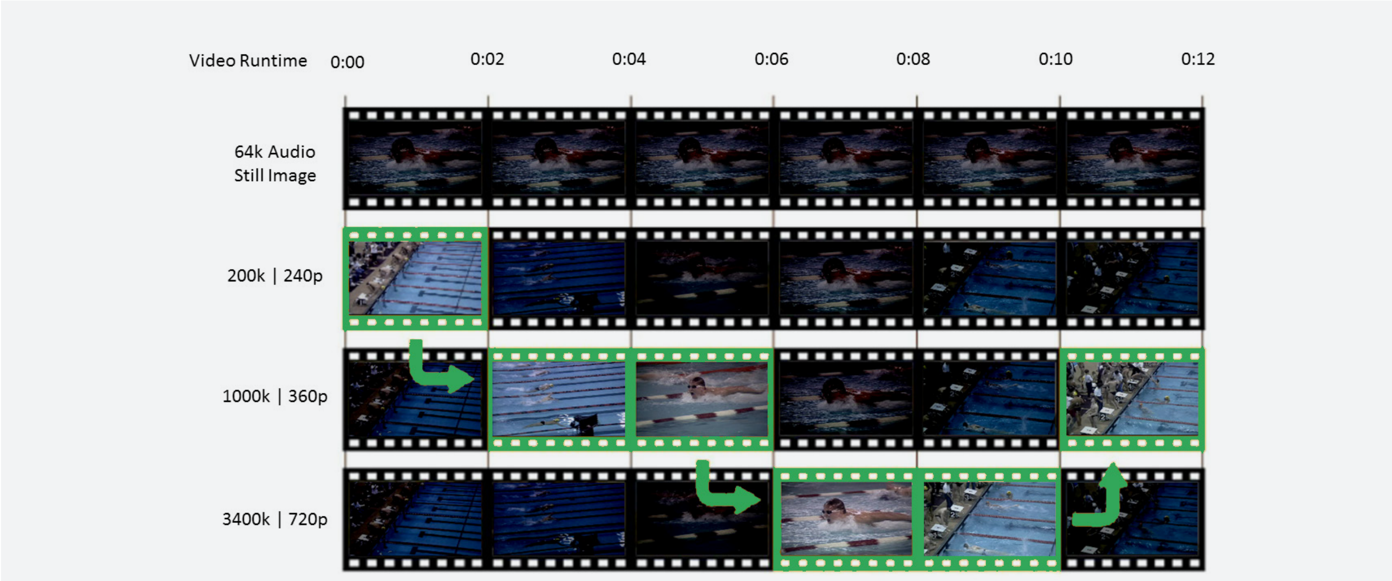


FIGURE 1. Client device switching profiles when bandwidth allocations change.

Background

Many of today's video and television delivery systems (e.g., cable TV, Netflix, Amazon, YouTube, etc.) are adding or switching over to an adaptive delivery system from the more traditional linear delivery systems. Although the linear system continues to serve us well with compressed-digital content, there are now an increasing number of people watching video and TV programs over IP on a wider variety of devices (e.g., smart phones, tablets, and smart TV's). Each one of those devices has differing performance capabilities and are most likely connected to links with varying data bandwidth availability. As a consequence, if the content being delivered to these devices was non-adaptive, (i.e., having a constant bit rate) then it is possible to experience data buffer over- or under-runs. This can severely impact the viewing experience with the most common and visible problem being the "Buffering" icon on the screen. This is due to a reduction in the amount of available bandwidth and an inability to maintain a real-time display (e.g., 29.97 frames per second). During this "Buffer…" window, the displayed video pauses while the additional frames are being received and buffered for playout. Once the buffer has enough data to start decoding in real-time again, the video playback resumes.

An elegant way to eliminate this "Buffering…" problem is to employ ABR techniques to deliver the content. ABR provides a mechanism for ensuring real time and continuous display of video no matter how much or how little bandwidth is available on the device being used. It does this by fragmenting the content into small 2 to 10 second fragments with several profiles (the same content at different bit rates) and then delivering the correct sequence of fragments at a bit rate (e.g., 200 kbps, 1 Mbps, 3.4 Mbps, etc.) that suits the available bandwidth.

One way to prevent buffer issues and maintain real-time video is to always keep the receivers' memory buffer about half full. If the buffer is filling up, then the device reduces the requests for additional video. If the buffer is draining and running low, then the device can ask to shift to a lower profile by requesting video which uses less bandwidth (i.e. video that is encoded at a lower bit rate). This ability to dynamically shift up or down in profiles is a critical task in an adaptive bitrate system and requires continuous feedback from the client device, back to the server. Also, the client device is always scaling the video to fit the client display window no matter if the profile is for 720p or down to a much small profile of 240p. The key here is to always maintain a real-time display of the video no matter how much or little bandwidth is available. Figure 1 illustrates the key principles behind this. In this example, the fragments are occurring on 2 second boundaries and it shows the seamless transition of the content on a device as it moves between different profiles. The same thing could happen on a device as it moves between different networks while the overall available bandwidth varies (e.g., switching between a Wi-Fi network and a cell phone network).

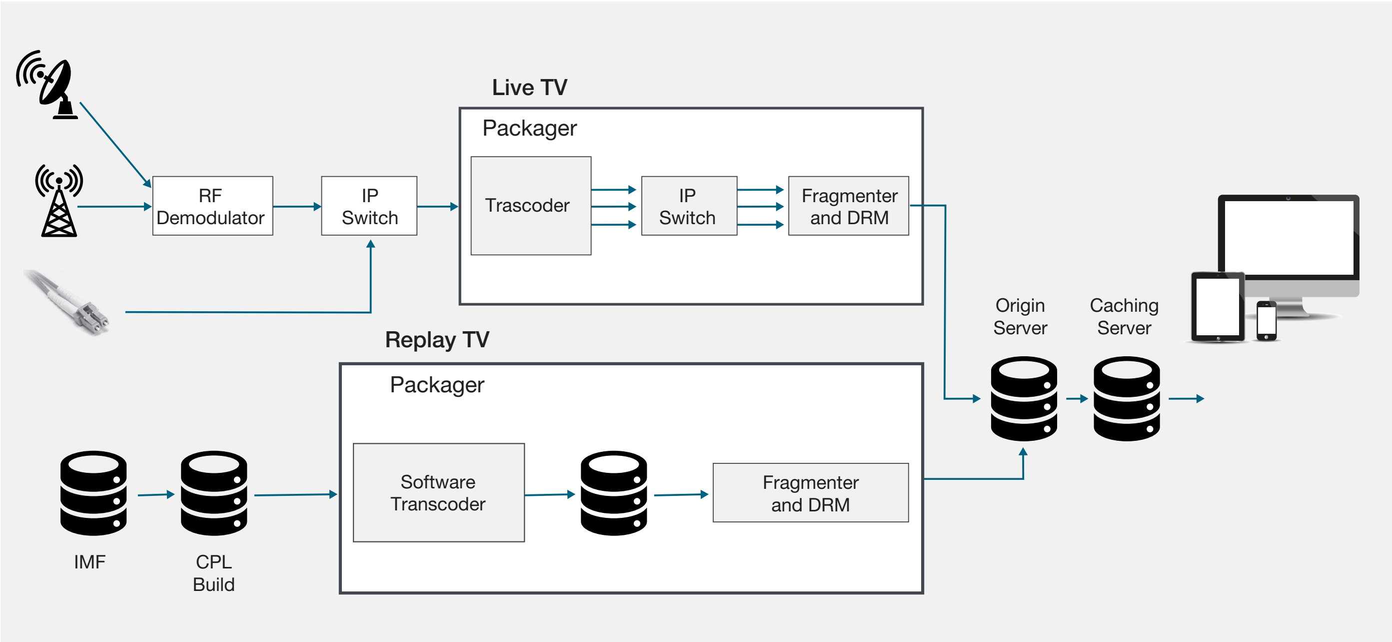


FIGURE 2. Example ABR system.

With ABR going mainstream now, we must not only ensure that the transcoders are creating the appropriate profiles, but that the video be monitored from acquisition (e.g., satellite, fiber, file) all the way to the origin server and content delivery network servers (CDN's).

Figure 2 is an example of an ABR system.

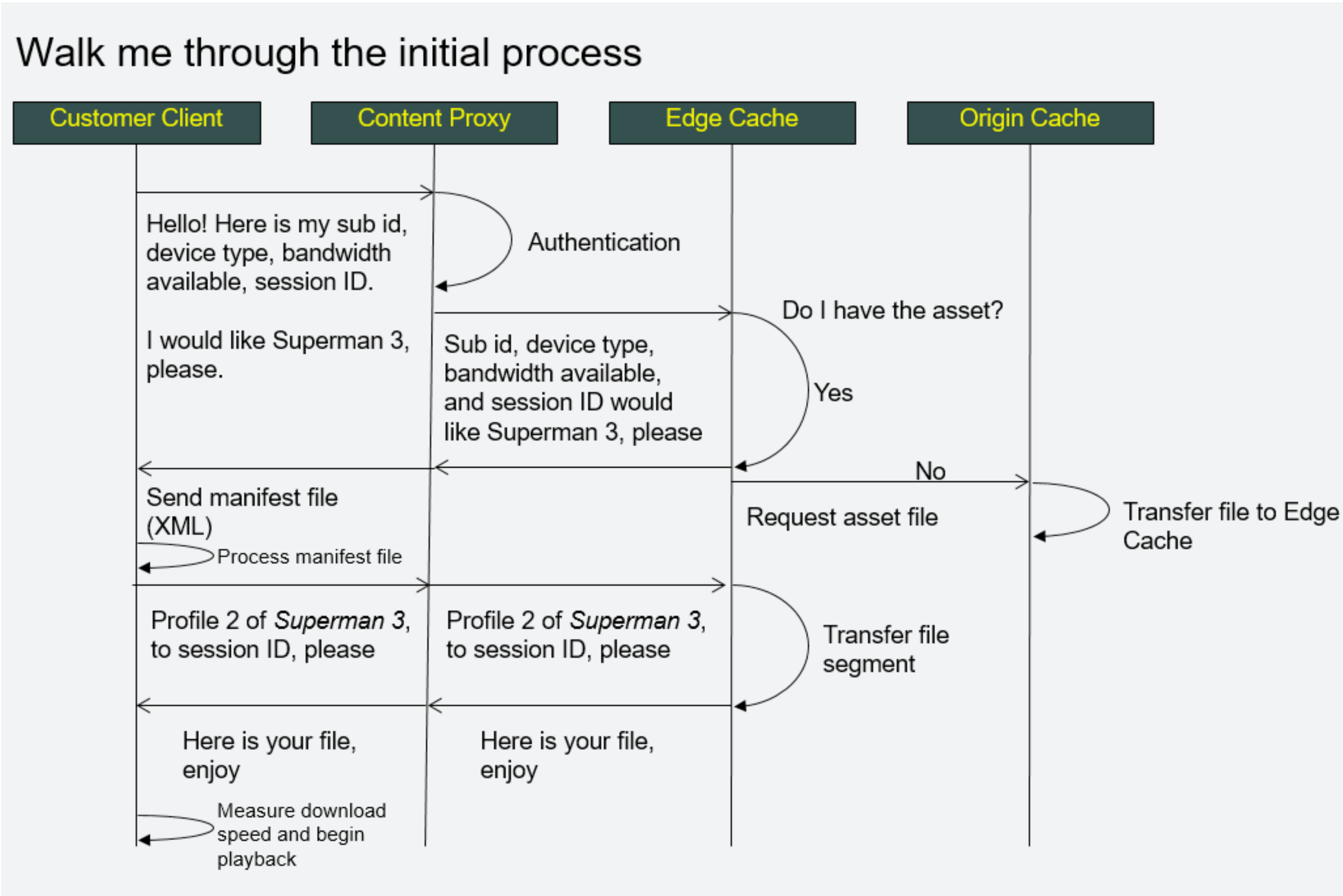


FIGURE 3. Initial transaction process between the client device and the ABR server.

How do I get my program?

Before a client device (smart phone, tablet, or smart TV) can begin displaying a program, several things need to happen. First, the client sends out an IP request to a URL that will authenticate, possibly redirect to a nearby server, and then download a manifest of the program profiles. Depending upon the available network bandwidth, the first profile chosen may be one of the lower resolution profiles to ensure that the initial part of the program can be received quickly, decoded, and then presented on the screen.

While the initial few seconds of the program are being decoded and presented, the client device makes a profile decision to increase or stay at the initial level, based upon the available bandwidth. If the receiving buffer was very slow to fill, then the next fragment of time requested will be for a lower profile (e.g., standard definition or less). If the buffer filled quickly and there is sufficient bandwidth, then the client may choose to make the next request for a higher profile (e.g., 720p or 1080p). This negotiation continues every few seconds to enable the client to maintain a real-time display with the highest quality possible.

Figure 3 is an example of the transaction process between the client device and the ABR server.

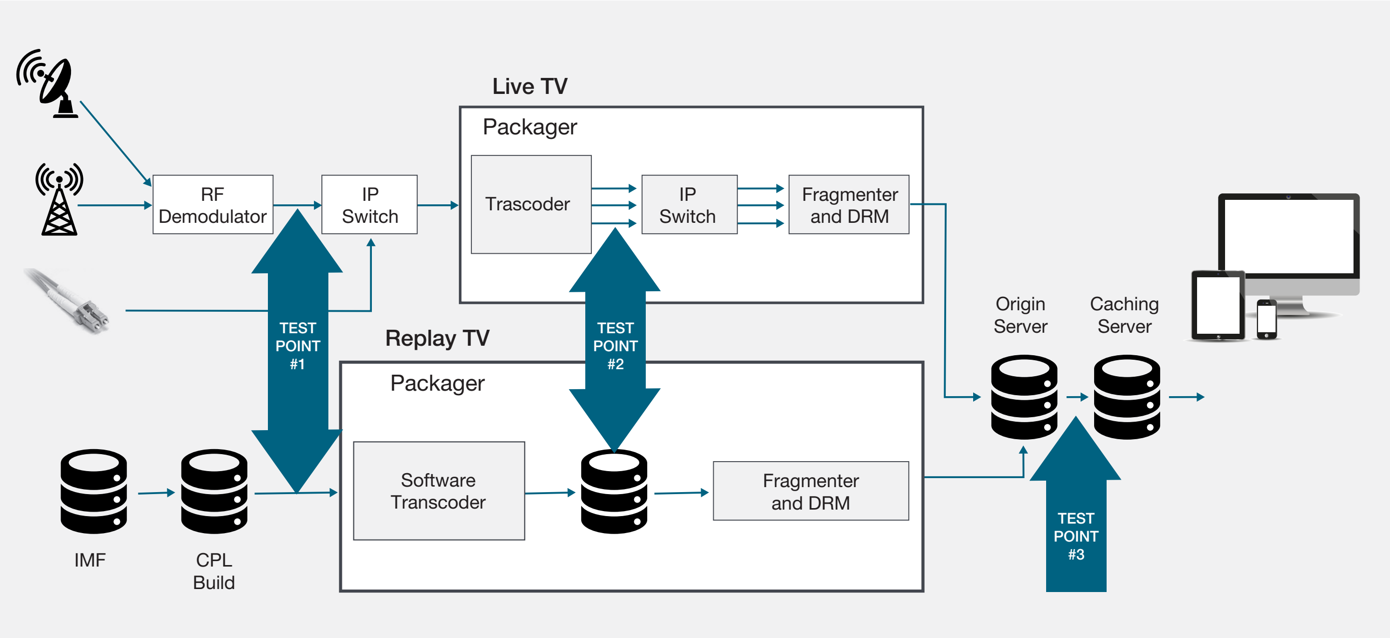


FIGURE 4. Test access points within a typical ABR system.

Ensuring a good viewing experience

As more and more people use ABR to watch TV or a special program, service providers need to ensure that the QoE is as high as possible. In order to maintain high QoE and proactively detect and repair any errors, we must be able to qualify the incoming or ingested content (RF or file transfer), as well as quickly isolate the faulty device or devices in the network. This requires taps or test points between each piece of equipment in the network. This often starts with the satellite signal or ingested file, and ends with the encrypted program from the origin server or content delivery network server (CDN). Figure 4 is a copy of Figure 2, but with the test points highlighted.

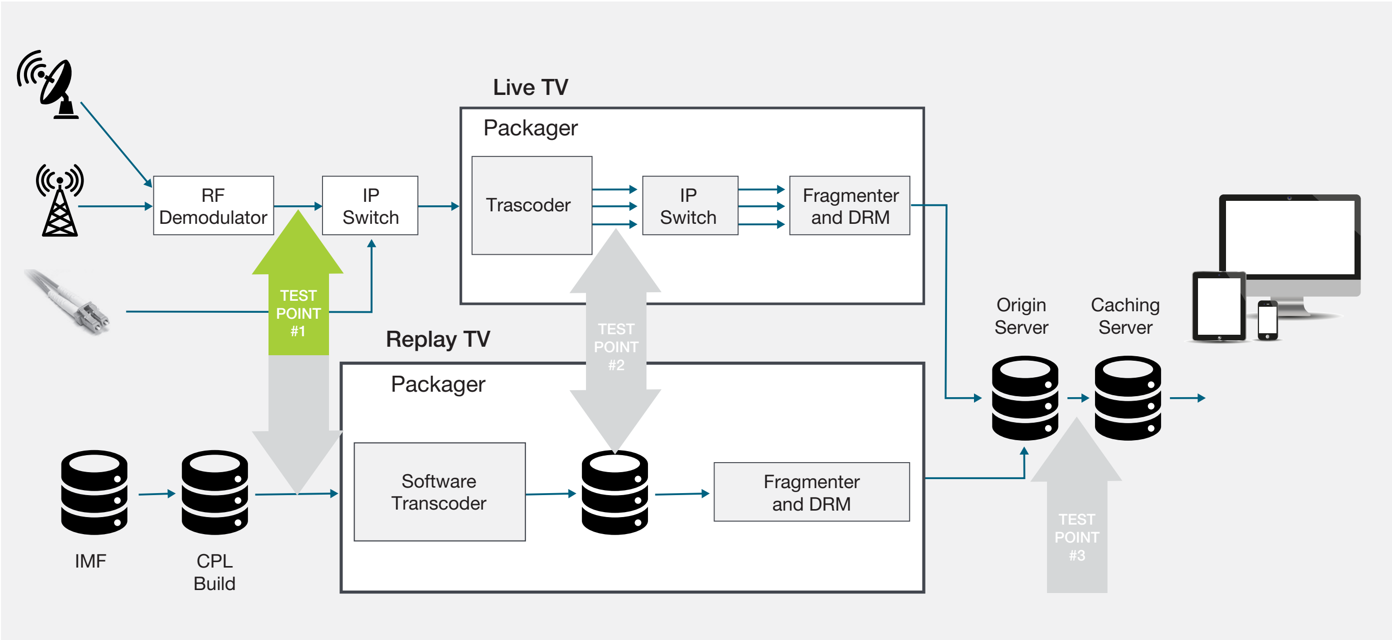


FIGURE 5. Test point #1 in a typical ABR system.

Test points within an ABR system

TEST POINT 1: TESTING AT THE RF DEMODULATOR

One reason to test here is that transmission errors are easy to detect and quantify. These errors will become hidden or much harder to trace back to their origin once the video and audio elements have been unwrapped or de-encapsulated from their previous transmission chain. Most transmission failures can be easily detected by looking at bit nine of each transport stream packet (Transport Error Indicator flag - TEI). A setting of “0” means that the RF demodulator correctly recovered all 188 bytes of that specific TS packet. A setting of “1” means that the RF demodulator encountered more than 8 bit errors in the TS packet and the Reed/Solomon algorithm could not correct every error.

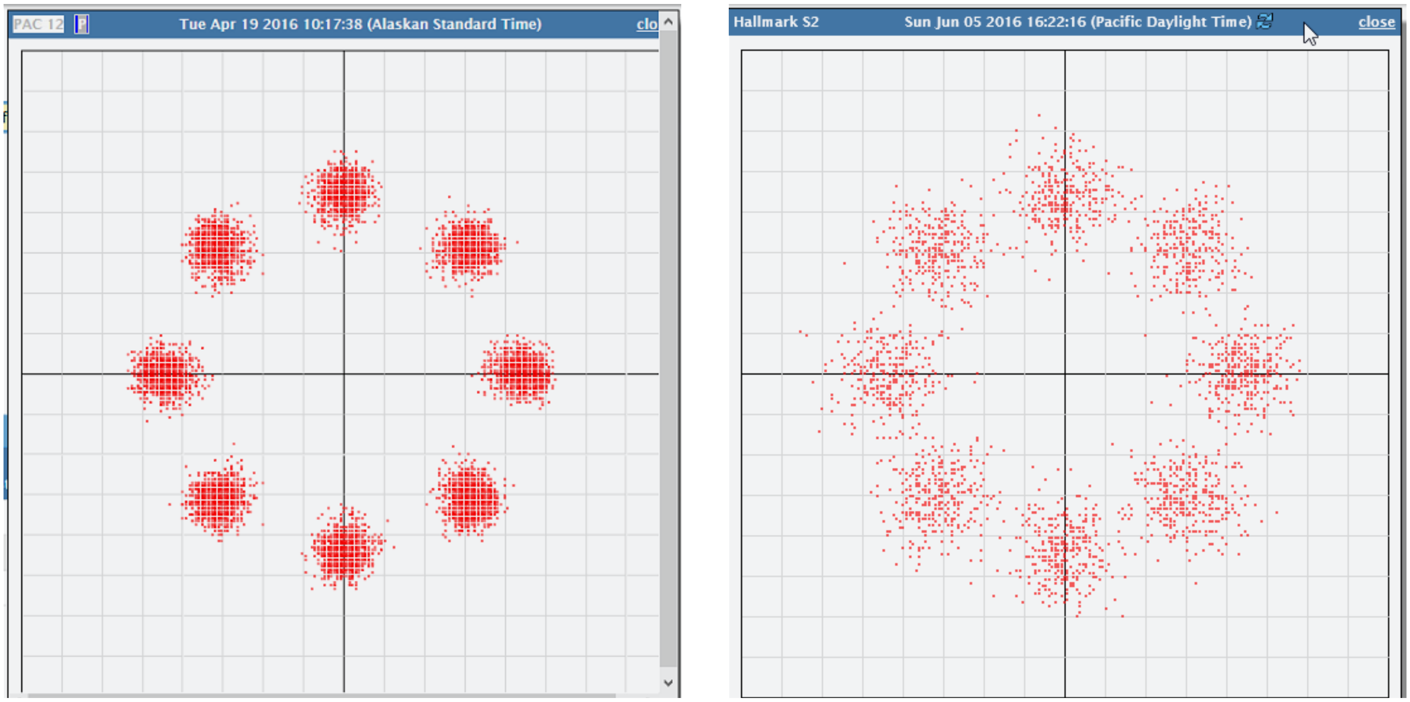


FIGURE 6. DVB-S2 signals. First with low noise, and the second with high noise.

Figure 6 shows a pair of satellite DVB-S2 constellations. Each 8PSK constellation is made up of 8 symbols where each symbol represents a short series of ones and zeros. The first picture has a tighter grouping of its symbols, which means it has less noise, higher modulation error ratio (MER), and a smaller bit error ratio. The second picture has a wider scattering of its symbols, and therefore, higher noise, lower MER, and a much higher probability of receiving bit errors in the demodulated stream. Signals with higher noise as in the second plot are more susceptible to errors and dropped symbols/packets. The key point here is that a symbol with high noise landing in the wrong target location, will result in a misinterpreted symbol (i.e., error). Errors can be reduced by using a larger antenna, increasing the signal level, or increasing the forward error correction (FEC) ratio at the transmit site (e.g., going from 5/6 to 2/3).

If an entire TS packet is lost due to poor RF or IP buffering conditions, then the TS continuity counter (CC) skips a beat. In both of these cases, TEI and CC errors, the result will be some type of audio or video impairment. It is critical to detect this error at the ingest point because once a remultiplexer device or transcoder receives this stream, it will rebuild all TS headers with new TEI flags and continuity counters thereby making it impossible to identify the point at which the video or audio element became corrupt.

As the content for the ABR system is acquired, we must ensure that it is interoperable with all downstream equipment. The first test category is quality of service (QoS). QoS tests look for signal fidelity as well as some high level protocol tests defined by the ISO/IEC 13818-1 (MPEG-2) and DVB TR 101 290 standards. This is verified by ensuring that:

1) The satellite or terrestrial RF demodulator has not enabled the Transport Stream (TS) Error Indicator (TEI) bit. See Figure 7, TR 101 290 Row 2.1

2) The RF demodulator did not receive discontinuities in the TS packets. See TR 101 290 Row 1.4

3) The acquired stream is free from audio and video syntax and semantic errors for both live and file-based content. The syntax and semantics tests compare received codec commands and parameters against those defined in each codec specification. Illegal commands and parameters denote non-interoperability and need to be flagged as errors due to downstream video and audio decoder issues.

4) Test point one would also be a good place to check for video blockiness (i.e., over compression), frozen frames, and audio loudness. Anything caught here would help with troubleshooting when the end result at the client has blocky video or silent audio.

Figure 7 shown below is from a satellite signal over a one-hour period and includes a variety of DVB section errors as well as PCR interval and continuity counter errors. The CC errors are considered extremely bad due to the fact that they denote a missing packet, and the decoder will struggle or fail during the decode process. PCR errors are not good either, but treated at a lower priority due to the filtering functions built into each set top box, or TV receiver.

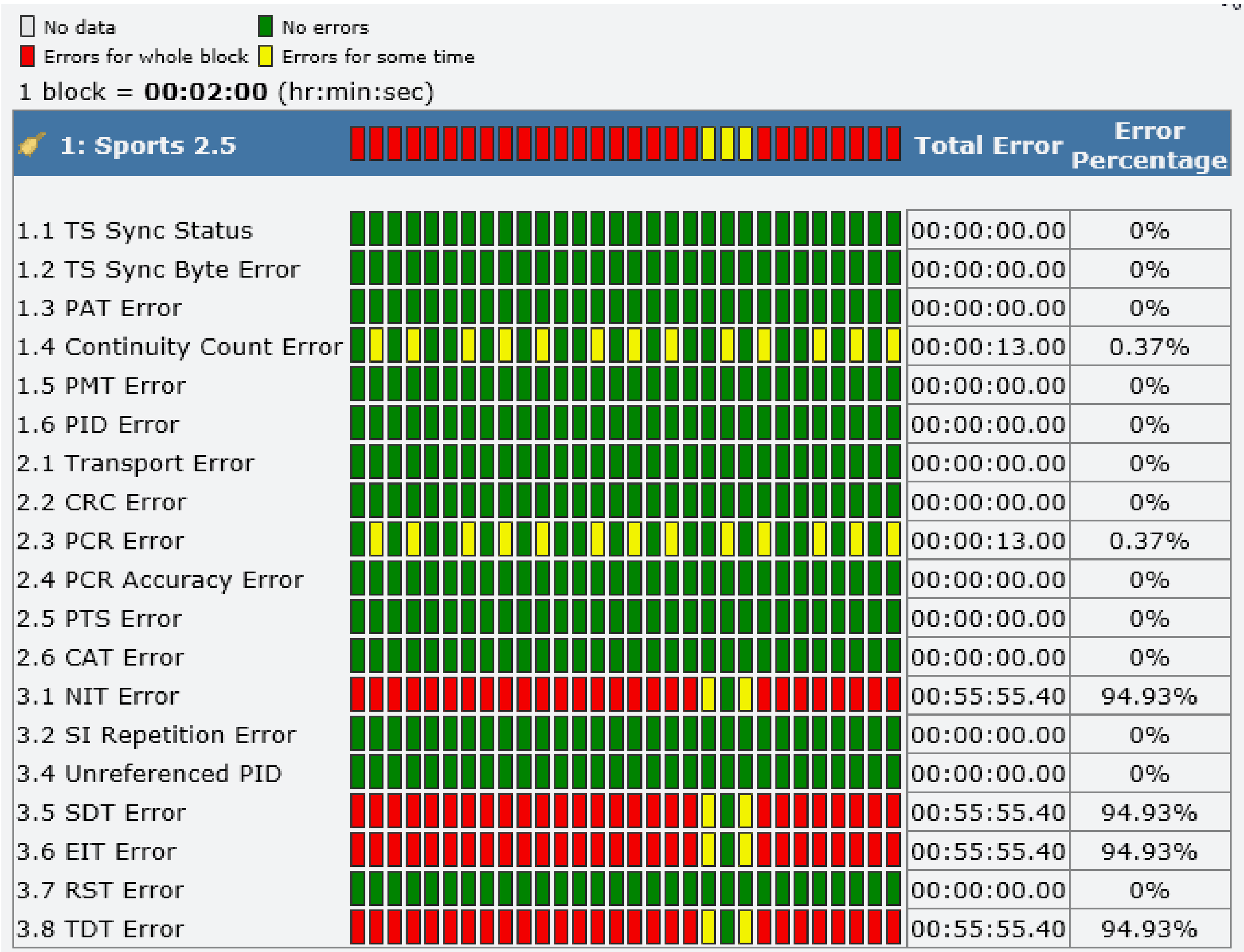


FIGURE 7. Satellite signal with several TR 101 290 errors.

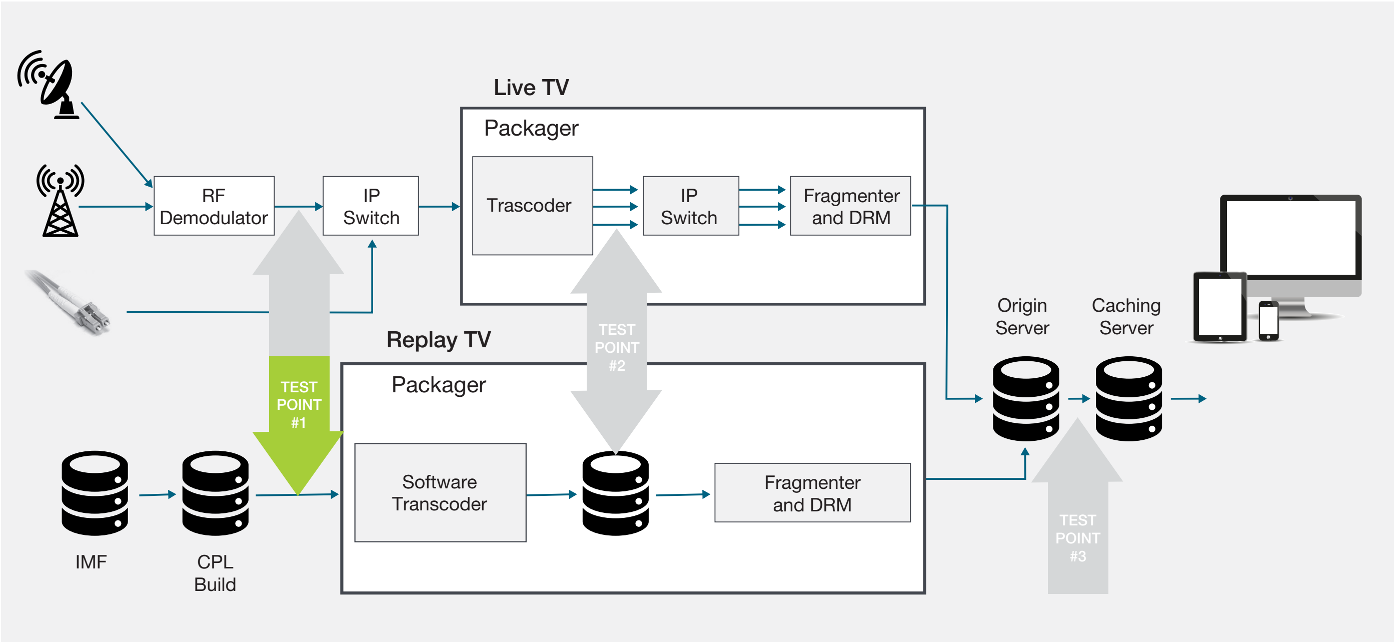


FIGURE 8. Test point #1 highlighting ingest of file-based content in a typical ABR system.

Another aspect to ingest or content acquisition is file-based. This is where the entire program, event, or movie has been software encoded in non-real-time and delivered to the service provider over the network as a large file. At test point 1, files are often received by file transfer protocol (FTP) and stored for near-term use. These source files are usually encoded at very high rates (e.g., HD or 4k at 300 Mbps) and are not for subscriber viewing. A popular format for these files is interoperable master format (IMF). This format will include a composition play list (CPL) which includes reference to its video, audio languages, captioning, and ancillary tracks. Reference the link to the Tektronix 4k poster (See Appendix) for more details.

Each ingested file will be used as a reference for the transcoder to create multiple profiles that can be easily transmitted (lower bit rates, higher compression). Before each reference file goes to the transcoder, each file should be tested for compliance to ensure that it is interoperable with any downstream decoding device.

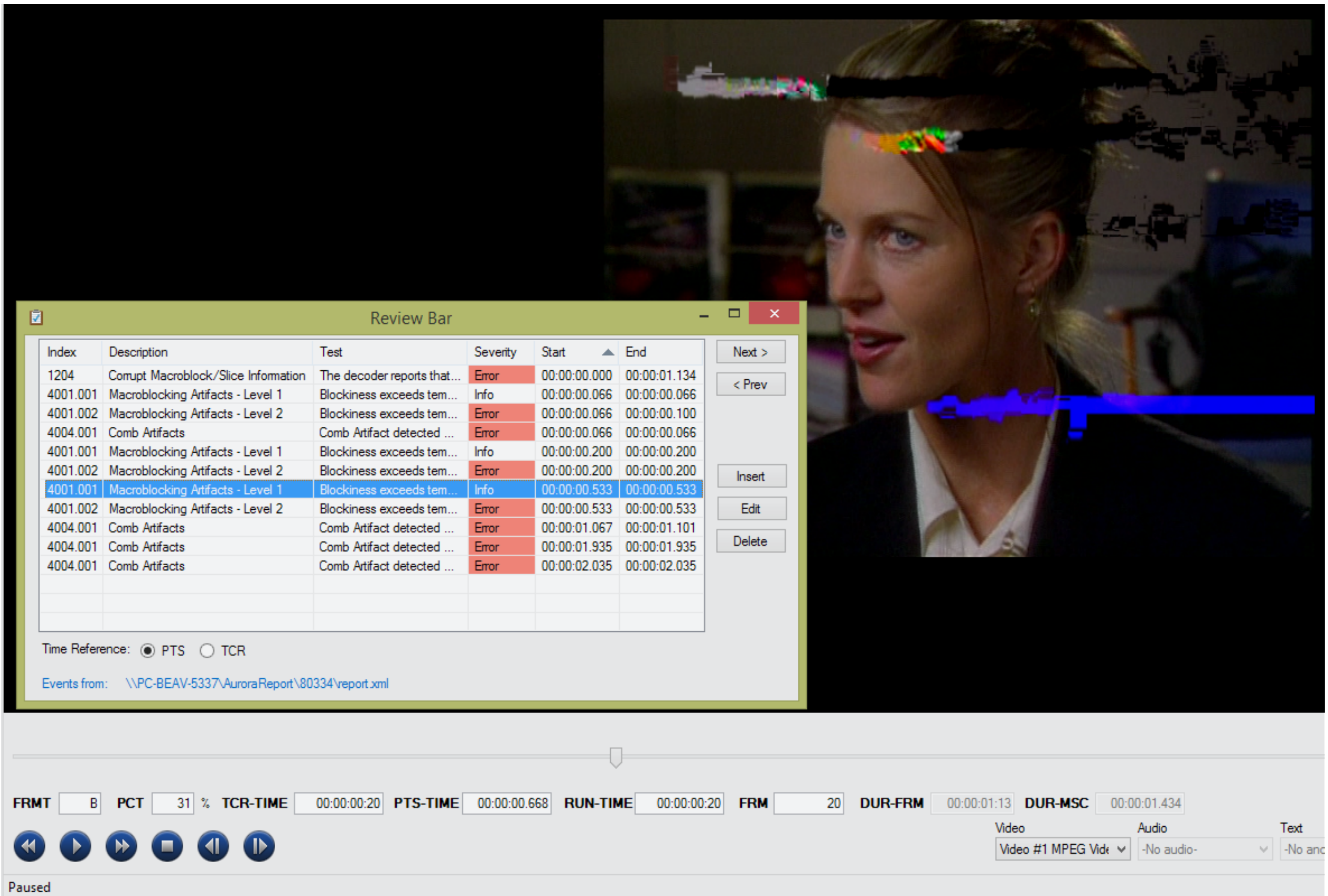


FIGURE 9. Ingested reference file that is not 100% interoperable.

If the source file is encapsulated using the ISO/IEC 13818-1 Transport Stream format, then the TR 101 290 tests should be applied. Also, the syntax and semantics tests are necessary to ensure that the source file will be interoperable with all downstream decoders and transcoders. It can be assumed that the source file has a very high quality of experience, but it is still important to check for errors. Finally, it is prudent to also check for blockiness, frozen frames, and that the audio-loudness levels are within specification. Figure 9 shows an example of a source file that included a few syntax errors in the middle of a frame. Due to the highly compressed nature of MPEG video, a single video error can cause artifacts in several subsequent video frames. Figure 9 shows a software analyzer triggering on frames that caused the video problem.

Once tested, each file can be moved to another folder or drive for transcoding, or off to a quarantine folder for files that fail the compliance or quality tests.

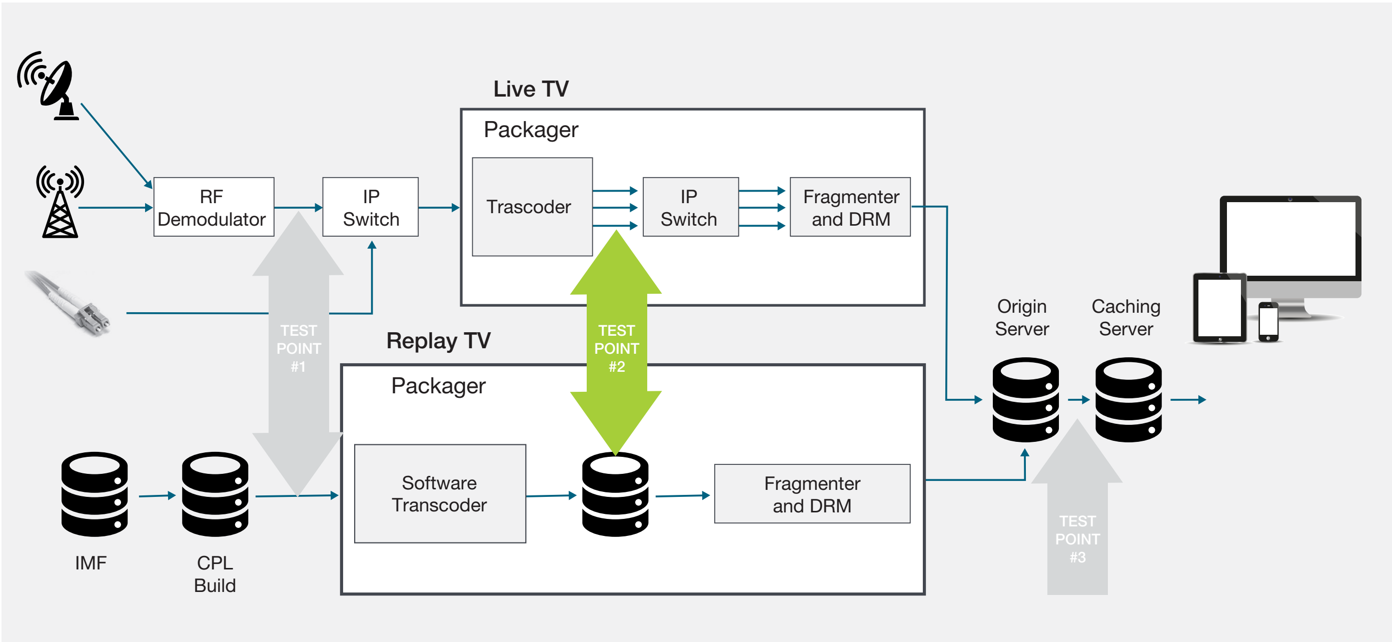


FIGURE 10. Test point # 2 in a typical ABR system.

TEST POINT 2: TESTING AFTER THE TRANSCODER

The next step in the ABR system is to transcode the program from its incoming format, to a newer codec format (e.g., H.264) at a higher compression rate. For both live events (e.g., sports) and file-based, each input stream or file will result in an array of many outputs or profiles (e.g., low, medium, high, etc.). Each of the new streams (profiles) should be verified for its rate, format, syntax and semantics, blockiness and loudness, as well as making sure the new reference frames are time-aligned across each of the profiles. These new reference frames (instantaneous decoding refresh – IDR and encoder boundary points – EBP) should occur at predetermined intervals. These intervals or boundaries are the points at which the ABR profiles can be switched while continuing to provide a seamless viewing experience.

FIGURE 11. 50 Mbps source MPEG-2 HD file (subset within one frame).

FIGURE 12. Action scene transcoded to 3.5 Mbps.

One of the biggest problems with video compression is blockiness. This is due to the encoder not having enough bandwidth to main a high QoE. The problem here is that every encoder will react differently to the same content. Also, the same set of encoders with different levels of firmware will react differently too. The most common issue is that the video frames look clean (at any rate) without any blockiness as long as the content does not include fast action scenes. To emphasize this point, Figures 11 and 12 look at a video frame from a short action-scene. In both cases, we have zoomed in on the center of the frame to highlight the pixels and blocks (blocks are a group of pixels, e.g., 8x8). Figure 11 is from the source file at 50 Mbps using a MPEG-2 codec. The details look just as they did on the film. It is not easy to find any groupings of pixels within blocks.

Figure 12 is from the same point in the file, but after the video had been transcoded to a much lower rate. Notice that the background sky is slightly blocky, while the hand, arm, and other objects are very blocky. This is due to insufficient bandwidth to support all of the action or movement in the video.

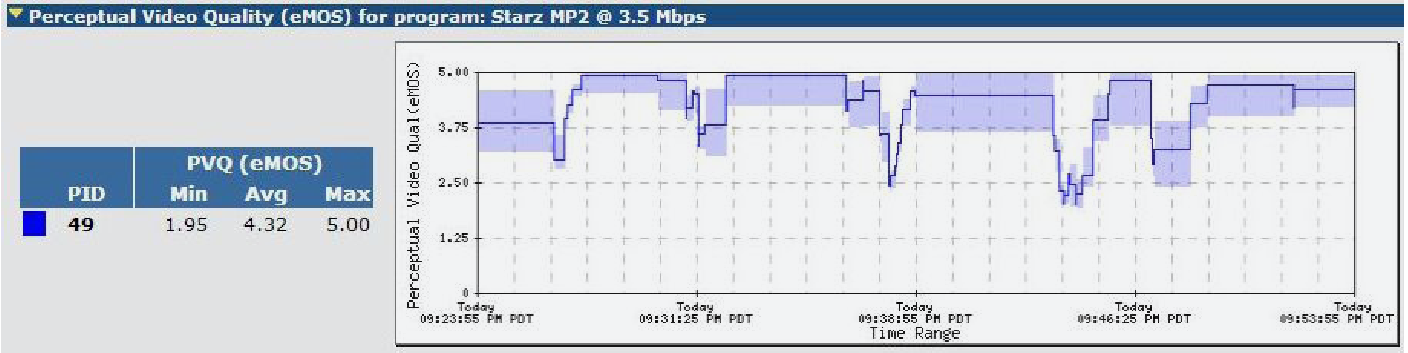


FIGURE 13. 3.5 Mbps constant bit rate video. High quality during slow scenes, and blocky during action scenes.

The video scenes just before and after the action scene had very little movement and were therefore much easier to compress at the same 3.5 Mbps rate (no blockiness detected). As an example of this sequence, Figure 13 shows a blockiness rating of a 30-minute period from within the movie. The very high levels of 5.0 were due to the scenes being easy to compress (little movement). The dips down to 2.5 were due to the fast action scenes as shown in Figures 11 and 12 (pirate cartwheeling into the air).

With all video, there will be scenes with little movement that are easy to compress, while other scenes will include fast-action scenes that are harder to compress. Finding the correct balance with all of the different codec settings is the challenge. Key items that effect the end quality are the bandwidth, size and type of group of pictures (GOP), and noise reduction. Some service providers reduce or subsample the number of horizontal pixels (e.g., 704 becomes 352) and then let the receiving device interpolate in the missing columns. This could cut the required bandwidth in half. The only down-side here is that very high frequency content (moving grass blades) may end up being softened or averaged out (e.g., solid green area). In any case, it is always wise to check for blockiness each time the video is encoded or transcoded.

Packager

At the heart of any ABR system is the packager. The packager performs three main functions. It will transcode the input content into multiple bitrates (on many systems there can be 8 different bitrate profiles produced). Next, the packager will fragment the profiles into 2 to 10 second blocks. Finally, it will (in many but not all cases) encrypt the fragmented profiles ready for delivery to the origin servers or Content Delivery Network (CDN). In some cases, the transcoded output is accessible for testing, and in other cases it is only accessible after fragmenting and encryption.

The result is that each profile of each stream will reside in a separate folder with many short transport stream files. The collection of these new folders will include a manifest file to describe the contents of each folder/profile. In the case of a server using digital rights management (DRM) software, it is possible to test the manifest, profiles, and the video/audio quality using DRM within the monitoring equipment. This final solution will allow the test equipment to view the same content a subscriber will see.

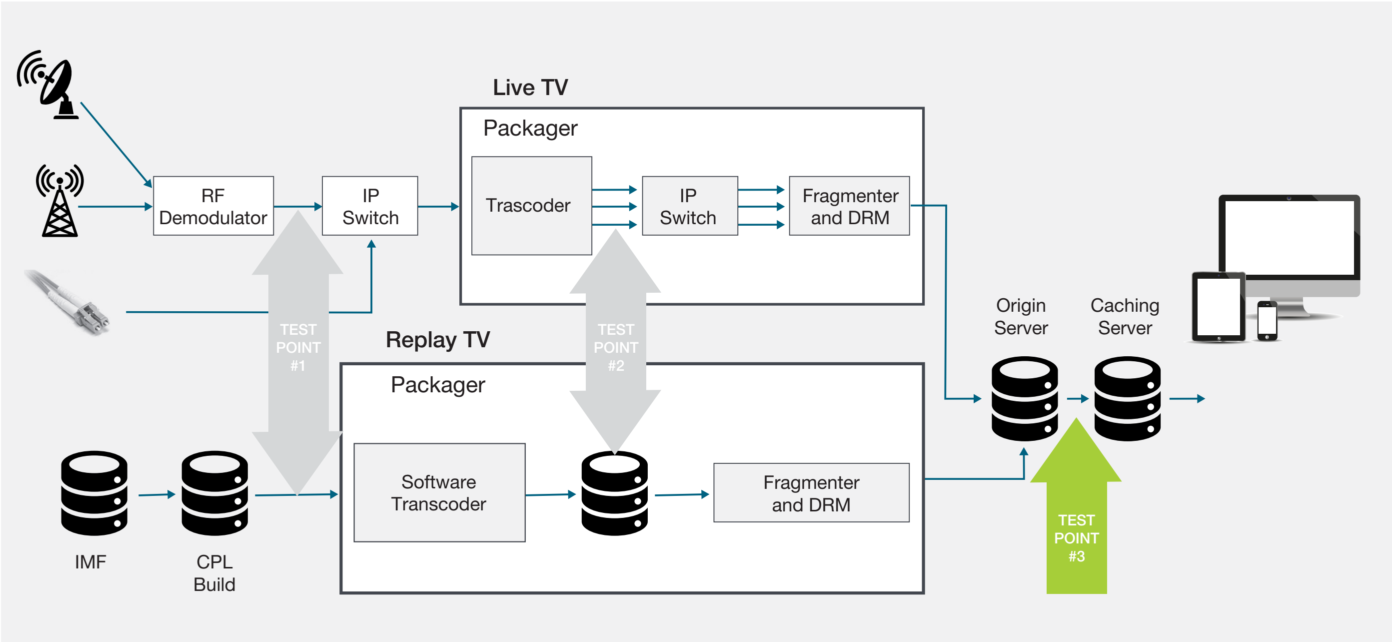
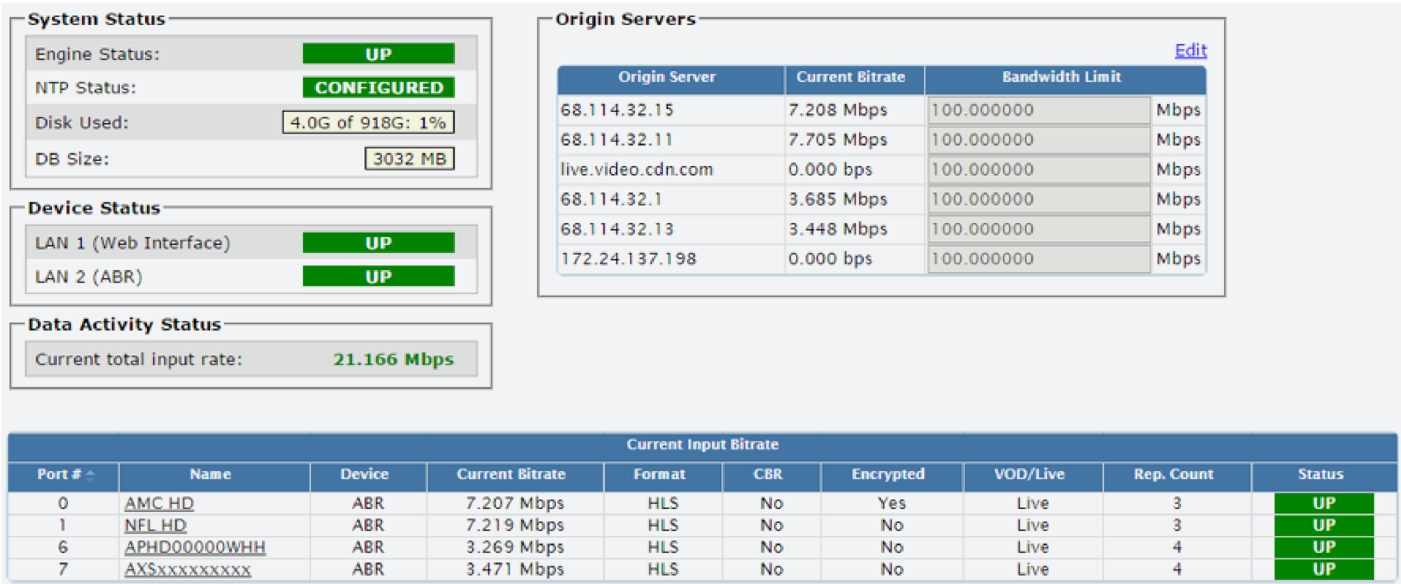


FIGURE 14. Test point #3 in a typical ABR system.

TEST POINT 3: TESTING AT THE ORIGIN AND CDN SERVERS

Once the TV and video programs have been placed onto the servers for playout, we can now monitor the manifest files that describe the multiple profiles for each program. We can also check the latency and bandwidth of the requests, and the QoE of the program based upon decrypting the content. In most cases, it would not be wise to use a single server (i.e., origin server) for all subscribers. For large systems, it is important to push the content as close to the subscriber as possible. This means making multiple copies of the most popular programs and storing them at caching sites around the region. Testing all of the content at all of the sites throughout every region would be great, but most service providers tend to focus on the content at the origin server.

The first test should always be to verify that the manifest and associated profiles all agree with each other. This can include syntax as well as defined bandwidth for each profile. It is also critical to alert when we see the requested fragments (from a subscriber) taking longer to arrive than their runtime is allocated for. For example, it should never take more than 10 seconds to download content that only plays for ten seconds. If this were the case, we would not be able to play video at real-time rates.



System Status

Engine Status:	UP
NTP Status:	CONFIGURED
Disk Used:	4.0G of 918G: 1%
DB Size:	3032 MB

Device Status

LAN 1 (Web Interface)	UP
LAN 2 (ABR)	UP

Data Activity Status

Current total input rate:	21.166 Mbps

Origin Servers

Edit

Origin Server	Current Bitrate	Bandwidth Limit	
68.114.32.15	7.208 Mbps	100.000000	Mbps
68.114.32.11	7.705 Mbps	100.000000	Mbps
live.video.cdn.com	0.000 bps	100.000000	Mbps
68.114.32.1	3.685 Mbps	100.000000	Mbps
68.114.32.13	3.448 Mbps	100.000000	Mbps
172.24.137.198	0.000 bps	100.000000	Mbps

Current Input Bitrate

Port #	Name	Device	Current Bitrate	Format	CBR	Encrypted	VOD/Live	Rep. Count	Status
0	AMC HD	ABR	7.207 Mbps	HLS	No	Yes	Live	3	UP
1	NFL HD	ABR	7.219 Mbps	HLS	No	No	Live	3	UP
6	APHD00000WHH	ABR	3.269 Mbps	HLS	No	No	Live	4	UP
7	AXSxxxxxxxxx	ABR	3.471 Mbps	HLS	No	No	Live	4	UP

FIGURE 15. ABR monitoring equipment summary page showing four programs from multiple servers.

When testing at the origin or caching servers, we want to test everything, but we do not want to create a scenario where the monitoring equipment requests more content than the network will allow. Also, we would not want to consume so much bandwidth that the subscribers would not be able to download and watch their requested programs. Therefore, the monitoring equipment should be configured with maximum thresholds for each server to limit the amount of content being pulled from each server. Figure 15 shows that each server will not be allowed to send more than 100 Mbps each. It also shows that there are four different programs being tested with some having three profiles or representations (e.g., low, medium, and high), while the other two have four representations. The term “representation” comes from the DVB DASH standard, while other standards use the term “profile”.

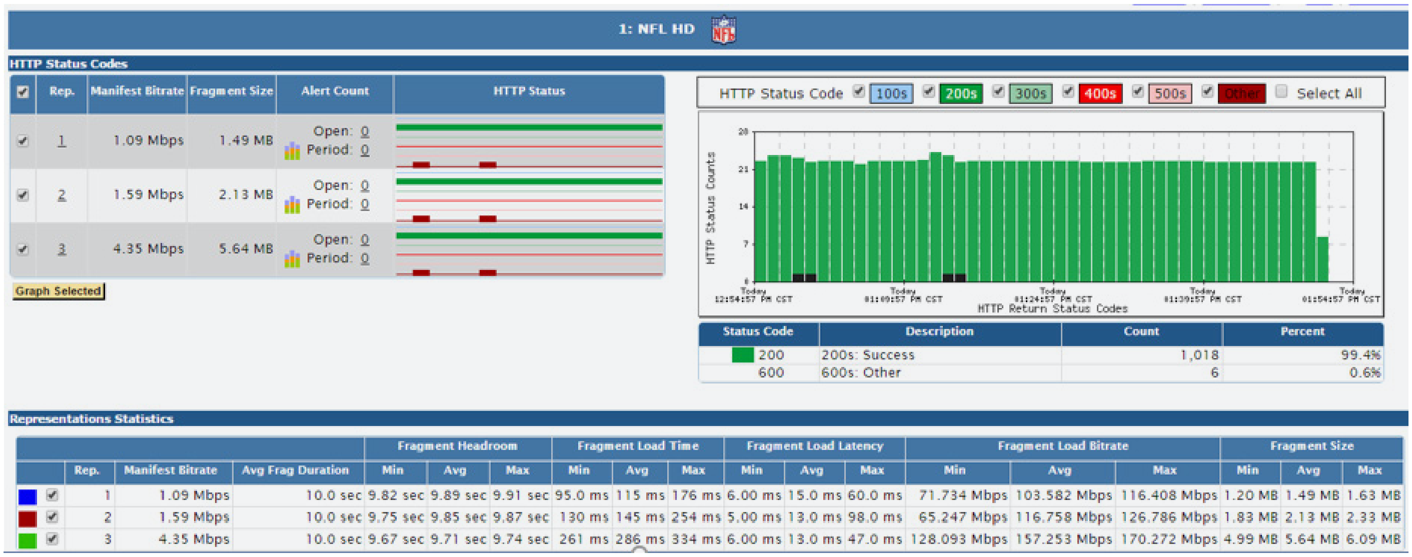


FIGURE 16. HTTP statistics from a program. The green HTTP 200 series codes signify successful transactions.

One key point in maintaining a high quality of experience ABR network is to make sure that the subscriber can download the small fragments of video quicker than it takes to play each fragment. Figure 16 provides valuable statistics showing timing, latency, and rate details for each profile. These numbers will help a service provider balance the load of the server. Triggers can be set to automatically alert when critical thresholds are crossed.

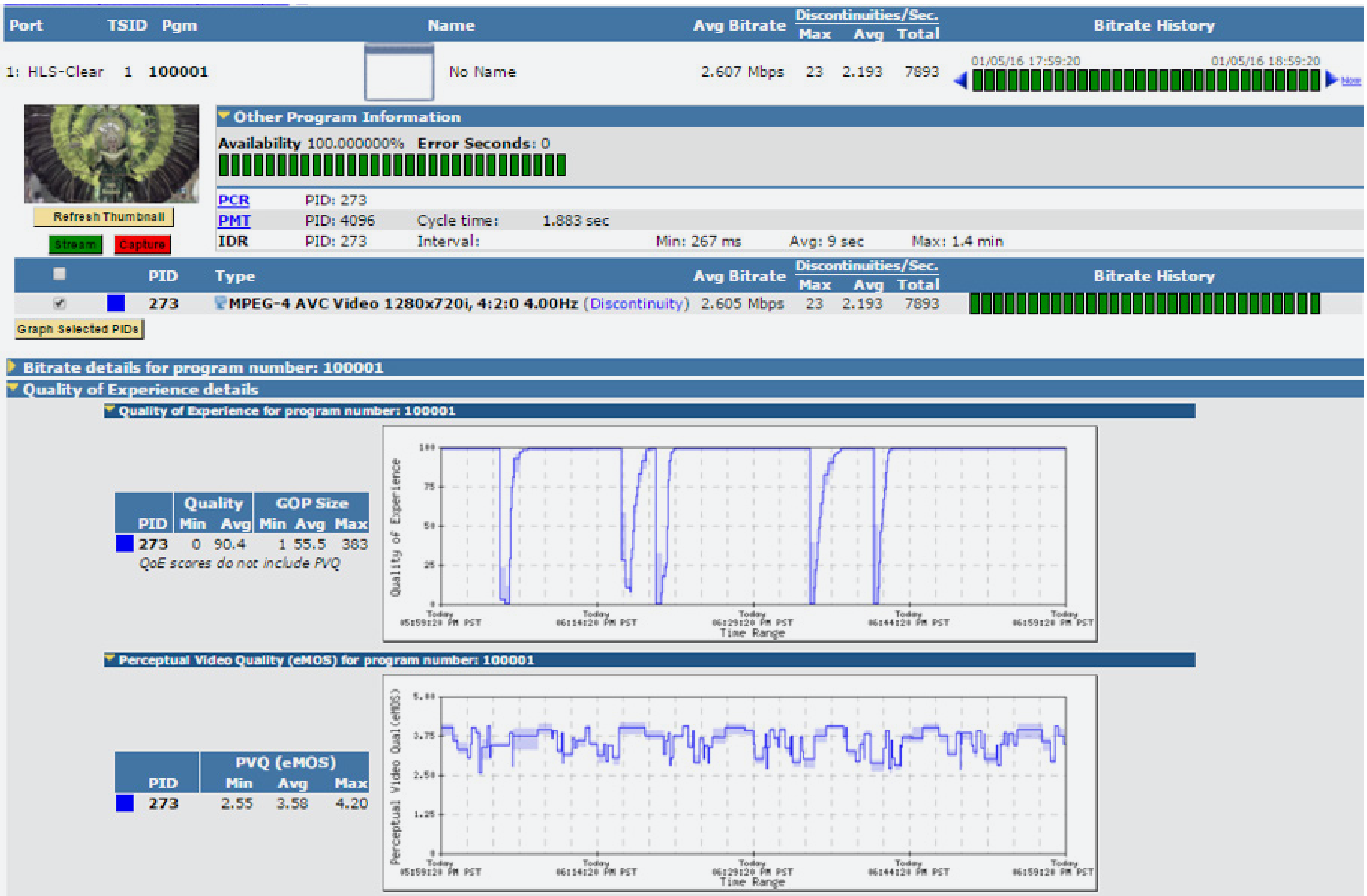


FIGURE 17. HLS content being measured for QoE as well as blockiness.

To complete the end to end quality of experience for ABR content, the monitoring equipment should decrypt and decode the live pictures and audio from the origin or caching servers. In most, but not all cases, the content is encrypted. With DRM support, monitoring equipment can decrypt each program and then look at the same video and audio available to subscribers (for every profile). The bandwidth for each representation should be very stable and consistent over time. The quality of the decoded video and audio should be good as well. Figure 17 shows one of the many representations from a manifest file that has been tested. In this case, we can see the video thumbnail and its program quality rating. These features may be used for troubleshooting and diagnostics, as well as long-term monitoring with triggered alerts.

Conclusion

In a typical ABR system there are three main areas to test and monitor: 1) at ingest looking at live and file-based content, 2) after the content has been transcoded, and 3) post-packager at the origin servers and content delivery network. At each of these test points it is important to monitor using a combination of QoS and QoE tests for all available profiles. Testing the content at the acquisition or ingest points will ensure that what is going into the system is a known good entity. Monitoring the transcoded content will verify that the quality is good and monitoring the IDR/EBP reference points will ensure seamless profile switching. On the delivery side, service providers need to test that the content will be available when requested and that it will play successfully. With consumers demanding content anywhere, on any device and at any time, you want to make sure that the viewing experience is simple and error-free.

Appendix

Delivering 4k Ultra HD poster:

http://www.tek.com/document/poster/4k-ready-set-go-delivering-4k-ultra-hd-television-using-h265-hevc

**Types of errors that cause QoE issues
(as shown in the Tektronix QoE poster):**

http://www.tek.com/document/poster/guide-understanding-qoe-improve-viewer-experience

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