How OTT Services Can Match the Quality of Broadcast

By Thierry Fautier

Abstract

Recent events, such as the 2018 FIFA World Cup, demonstrated that live over-the-top (OTT) experiences have some serious limitations, including low quality on TV sets and a delay of more than 30 sec compared with broadcast services. If the industry does not solve those problems, they could halt the development of live OTT offerings. This article analyzes the current challenges involved with delivering live OTT services and will describe solutions that are available today, such as content-aware encoding, artificial intelligence, and low-latency common media application format (CMAF). In addition, this article will present new concepts that can be deployed as part of an end-to-end OTT solution to further optimize quality of experience for OTT services on existing infrastructure [i.e., headend, content delivery network (CDN), and devices].

Keywords

Broadcast, common media application format (CMAF), delay, latency, live, over-the-top (OTT), quality, quality of experience (QoE), video

Introduction

Over-the-top (OTT) is becoming more and more mainstream and is even used now to watch live services on TVs. In the U.S., among Sling, DirecTV Now, Hulu, YouTube, and Sony Vue, there were more than 9 million OTT subscribers by the end of 2018.[1] Of course, the expectation of OTT consumers to have an experience similar to broadcast TV is on the rise, and the industry has to provide a solution to meet this expectation. This article first defines what a broadcast delivery network is along with what defines OTT today. Then, it looks at different ways of delivering OTT services, analyzing each element of the network's contribution to the quality of experience (QoE). Next, this article will look at the technology that is being deployed, such as content-aware encoding (CAE) and Motion Picture Experts Group (MPEG) common media application format (CMAF), and examine a more holistic approach that takes into account the overall network analytics so that the client receives the best performance.

Over-the-top (OTT) is becoming more and more mainstream and is even used now to watch live services on TVs. In the U.S., among Sling, DirecTV Now, Hulu, YouTube, and Sony Vue, there were more than 9 million OTT subscribers by the end of 2018.

Broadcast Delivery

A broadcast delivery network is a dedicated network that sends one piece of video content to many viewers and can, therefore, scale by adding more capacity for more subscribers, without affecting the experience. **Table 1** lists the different broadcast network options to distribute content at scale.

These types of networks deliver a similar QoE, which is considered the gold standard by today's consumers.

IP Delivery

IP can be delivered in multiple ways. As is the case with broadcast delivery, IP multicast is also very scalable, as only one stream is delivered to millions of subscribers. The other delivery mechanism used for all connected devices is the HyperText Transfer Protocol (HTTP), which relies on adaptive streaming or adaptive bitrate (ABR). OTT generally uses the unicast delivery protocol over unmanaged networks. In IP deployments, there is also a way of delivering HTTP adaptive streaming over managed networks. The different ways of delivering unicast to connected devices are summarized in **Table 2**.

Operators provide set-top-boxes (STBs) to consumers; therefore, they have more control over the experience.

Figure 1 describes the different network topologies.

Managed Network

In the case of ABR delivery over managed networks, the HTTP traffic is carried on a virtual local area network (VLAN) with a delivery priority (VLAN tagging) from the headend down to the device. Even if it is delivered on Wi-Fi, operators can prioritize the Wi-Fi traffic on their own gateway. In this configuration, the QoE is close to

Digital Object Identifier 10.5594/JMI.2020.2969763
Date of publication: 15 April 2020

TABLE 1. Broadcast delivery networks.

Network	Standards	Delivery Network	Client	Scaling
DTT	ATSC/DVB-T/ARIB/T-DMB	OTA	TVs	Spectrum capacity
Cable QAM	CableLabs/DVB-C	HFC	STB	Spectrum capacity
DTH	DVB-S (2)	Satellite network	STB	Spectrum capacity
IPTV	DVB IPI	IP multicast	STB	Network capacity

TABLE 2. Unicast delivery mechanisms.

Delivery Type	Service	Often Called	QoS	Access Network	Gateway	Device	App
Managed ABR	TV over IP	IPTV 2.0	VLAN dedicated to service	Operator network (DSL/ Fiber/DOCSIS)	Controlled by operator	Controlled by operator	Controlled by operator
Best effort ABR	TV over Internet	OTT	Best effort	Operator network (DSL/ Fiber/ DOCSIS)	Owned by consumer/ operator	BYOD	Controlled by Content provider
						Controlled by operator (1)	Controlled by operator (1)

IP multicast from the delivery point of view. Meanwhile, when traffic surges, if there is not enough network or streaming capacity, the servers will go to the lowest profile that enables smooth delivery. This is also called IP Television (IPTV) 2.0, and we see new telco deployments following this type of architecture.

Pure OTT

In the case of pure OTT, content providers use the public internet to deliver content to the end user, using HTTPs. Netflix and all of the OTT services use this mechanism. Owing to the growing concern of Netflix traffic, there is congestion at the interchange level, and in order to avoid endless discussions with internet service providers (ISPs) about the payment for traffic, Netflix is offering (for free) to put its own streaming server in the ISP PoP through the Open Connect initiative.[2] Based on the information shared by Netflix, the full catalog can fit on one server. With redundancy, this equates to two servers per ISP PoP. There is no way to compare the difference in QoE with or without Open Connect, but many in the industry agree that the Netflix quality is the best compared to OTT services from other providers. Hence, we believe Open Connect caching plays a vital role in that.

OTT with Managed Devices

Another aspect of unmanaged ABR is where the operator brings its own device to consumers. This is the case for

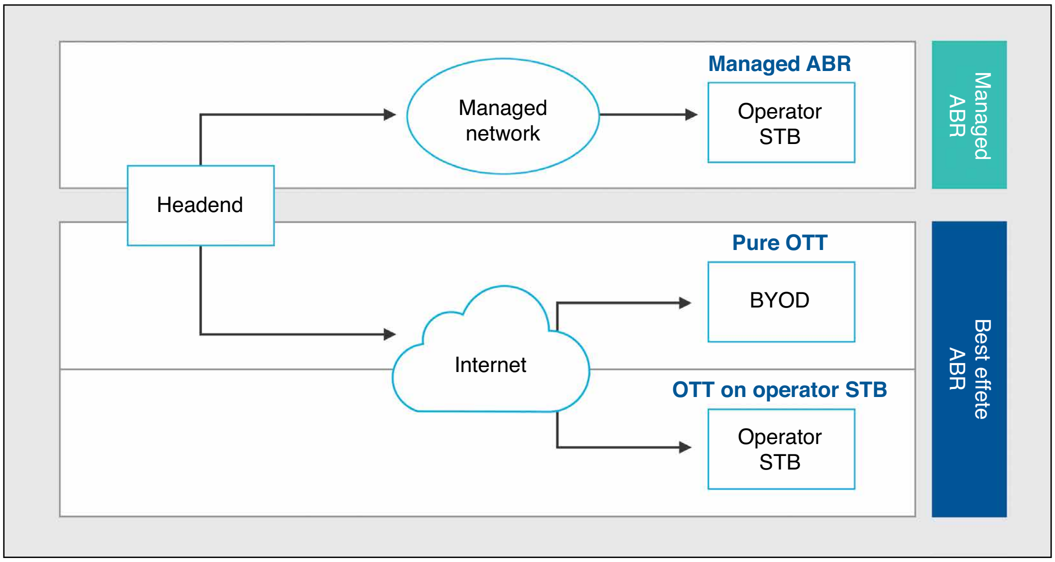

FIGURE 1. Unicast network types.

TABLE 3. Unicast deployment comparisons.

Service	Source	Network	Networking Characteristics	Gateway	Gateway to STB	STB
Managed	ABR headend	IP private network	DSL, FTTH, DOCSIS	Controlled by operator	Wired	Managed by operator
Pure OTT	ABR headend	Public Internet	DSL, FTTH, DOCSIS	Owned by consumer/ operator	Wi-Fi	BYOD

telcos that want to penetrate into the customer base of competitor ISPs or for OTT operators that want to better control the experience. This is a different case compared with the pure OTT one, as the operator fully controls the software stack running on the client and can, therefore, better control the user experience.

Comparison of Different Architectures

There are very few operators that have deployed an ABR service on their network as well as OTT. We have gathered some data coming from a commercial deployment of one operator operating exactly the same service on its own network with its device and on OTT through its competitor's network. **Table 3** provides the characteristics of these two deployments.

The difference in QoE (proprietary metrics defined by operator) between the managed and the OTT service is 300%. This is explained by the fact that on the managed side, the bandwidth can always be provisioned with the highest priority, there is no Wi-Fi interference and the client is fed with a wired Ethernet connection and is also managed by the operator. On the pure OTT side, the network is shared with internet traffic, the gateway does not give priority to the video service, Wi-Fi can create problems in a bad home network, and using a bring your own device (BYOD) leaves the operator at the mercy of the device's OS, even if the operator writes the app itself.

This example shows that a fully managed service has a much higher QoE, and this should give hope to IP operators (cable and telco) in their fight versus OTT operators that have to go through all the hurdles of a pure OTT system. This could also open the path to use the ISP managed network to host OTT services in the future. To mitigate the pure OTT situation, operators are now developing their own (Android TV) STB. This way, they can optimize the last part of the chain.

Network Delivery Aspects for ABR Delivery

This section will look at how each element of the network can have an impact on the QoE. Let us first review the end-to-end delivery system in **Fig. 2**.

Compression

Compression is the engine of ABR delivery. The lower the bitrate, the easier it is to deliver unicast to the device with the highest QoE. Nevertheless, if the bitrate is too low, the quality will suffer and thus the QoE will be degraded. This can be resolved by using the most advanced codec, such as High Efficiency Video Codec (HEVC), but the current licensing terms have slowed down deployments. However, several recent reports[3–5] show that by 2019, 63% of operators will have an HEVC service deployed. With that being said, in June 2017, HEVC garnered extra attention after Apple announced that it will support the video compression standard across all of its platforms, including Mac, Safari, Apple TV, and iOS11. This announcement was significant for HEVC, as iOS traffic accounts for about half of all video streaming over the internet.

In order to work around the HEVC licensing problem, many companies have developed what Netflix calls "per tile encoding" for video on demand (VOD) and what the industry at large is now calling "CAE," which supports both VOD and live applications. It was a great blessing for CAE when Apple announced, in 2017, support of variable bitrate (VBR) for the VOD and live encoding in iOS11.[6] The Ultra-HD Forum has identified the use of CAE for Ultra-HD delivery

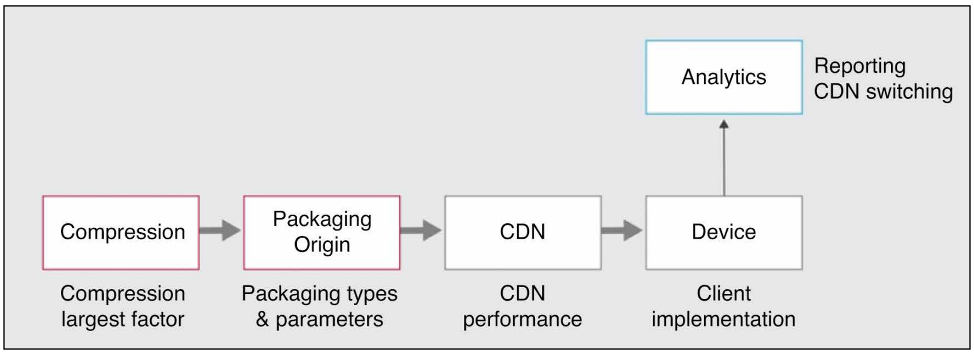

FIGURE 2. End-to-end QoE contribution.

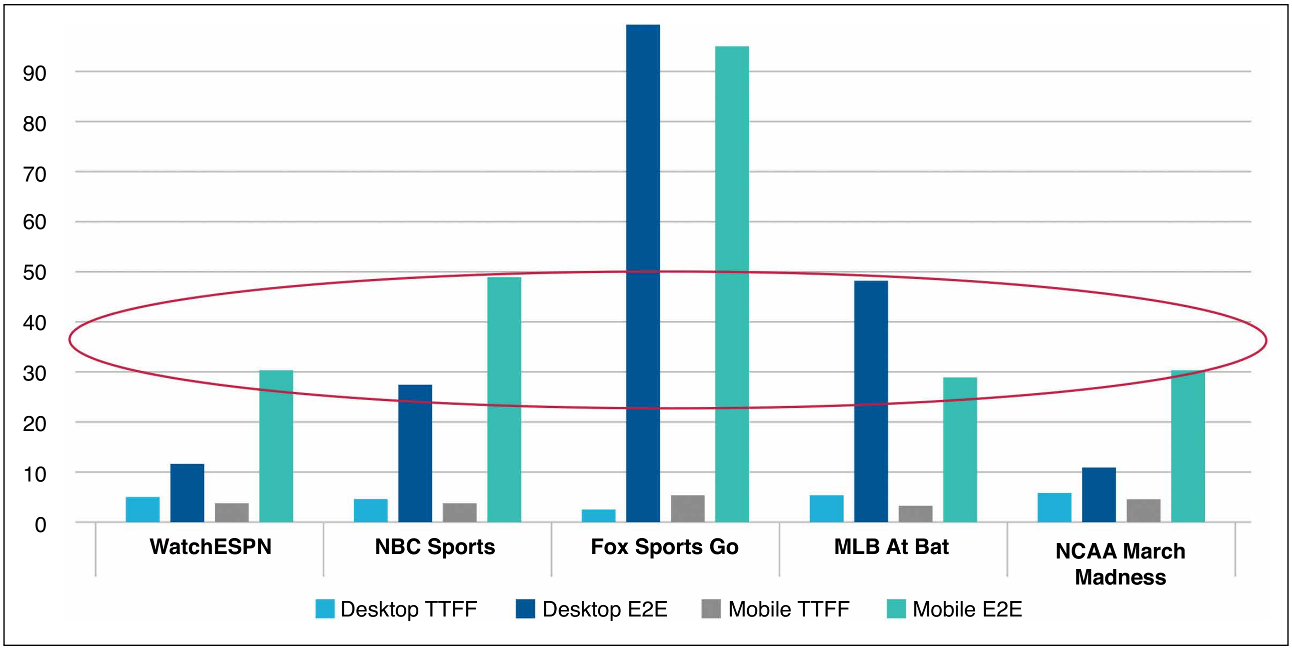

FIGURE 3. U.S. OTT latency (Courtesy: Wowza May 2017).

over the internet as critical and has included CAE in its Guidelines.[7] In addition, the Forum demonstrated the technology at NAB 2018 and IBC 2018, showing a consistent savings of 40% versus constant bitrate (CBR) for ultrahigh-definition (UHD) ABR using CAE with multiple vendors (BeamR, Brightcove, and Harmonic) across different applications (VOD and live). More details on how CAE works will be provided in the CAE section.

Packaging/Origin

The packaging technology used will have an impact on the QoE. Several reports have studied the differences between HTTP live streaming (HLS) and dynamic adaptive streaming over HTTP (DASH). The most recent one[8] gives a good overview of the different techniques that are used to deliver the best QoE, including the client behavior.

One of the biggest problems facing OTT QoE is the end-to-end latency. With current HLS or DASH implementation, the end-to-end delay is between 30 and 90 sec, as described in **Fig. 3**.

There are many ways of solving the latency problem, for example, reducing the segment size, moving to a different protocol like WebRTC, or using MPEG CMAF. Reducing the segment size (down to 1 sec) would increase the network traffic, may impact the video quality as it puts constraints on the compression schemes, and has so far not been deployed in any commercial system. Using WebRTC, which is an old protocol, has the disadvantage of not being cacheable with off-the-shelf content delivery network (CDN) servers. It requires dedicated infrastructure and has not been proven to scale for millions of concurrent sessions. MPEG CMAF will be presented in more detail in the section titled "Delay Impact on QOE."

CDN

CDN is a technology that is proven to work at scale for the most demanding events (i.e., the Super Bowl, Olympics, and FIFA World Cup). The most popular event where CDNs have been used for was in India with the Indian premier league (IPL) draining 4.8 million concurrent users.[9] To be efficient, a CDN needs to have enough streaming capacity as well as servers located as close as possible to the clients. Operators have come to the conclusion that some CDNs perform better than others during certain times of the day and in certain locations. This is why we have seen a CDN selector technology market segment develop, with some success. The concept is described in Ref. 10.

Another way of looking at CDNs is to build them inside of the operator's network, using either off-the-shelf technology from CDN vendors or technology developed by the operator itself like Comcast.[11] This approach offers the benefit of serving a certain type of traffic, overload can be off loaded to commercial CDNs, and in terms of depth in the network, the caching servers are located closest to the subscriber to ensure the best QoE. The drawback is that this is capex-intensive, as the operator needs to deploy the network and opex-intensive to manage the CDN 24/7.

Device

The device is an important element of the delivery chain, and there is a wide diversity between the native clients (i.e., HLS and Android) and the custom clients developed by client companies.[12]

The OTT clients own their ABR selection rules using a well-known family of algorithms (based on buffer occupancy or bandwidth estimation). Advanced clients also embed smart processing to reduce the startup time and end-to-end latency to the minimum possible.

The unique streaming optimization technologies developed by companies, such as Giraffic,[13] enable the client to fetch data based on rules, using transmission control protocol (TCP) multiconnection strategies.

The unique client-side-only streaming optimization technologies developed by companies, such as Giraffic, enable the client to fetch data based on rules and receive more robust TCP strategies. This technology gets a much higher bitrate on average than the classical approach. According to Giraffic, the client can fetch the data sometimes two to three times faster than the classical approach by using strategies such as TCP multiconnection and client-side congestion management based on variable byte range requests, as well as shaping the traffic ingested to the video player in order to facilitate better ABR switching decisions.

The downside of this technique is that potentially other devices in the home that are not enabled with such technologies might become more congested.

Analytics

Analytics can be of many types. They come with the CDN, and we have seen client analytics technology developed by several companies. Analytics can be used for business reports, which are of little use for QoE but can be used for more important technical reporting of key parameters such as startup time, buffering rate, standard definition/high definition (SD/HD) profile ratio, and profile switch.

Out of those analytics, the operator has a good view into the user experience, but there is no indication on what to change in the network and what parameters should be modified in the video delivery network to increase QoE. This will be discussed in the section titled “Network optimization.”

Compression Impact on QoE

CAE is one of the hottest technologies today in the encoding market, that was first introduced for VOD encoding by Netflix [14], and was released by encoding companies in 2018 using similar form of CAE technology, but this time applied to Live. The concept of CAE is that the encoding server looks in realtime at the video complexity and in realtime adjusts the encoding parameters to provide the best picture quality.

CAE works similarly to VBR for statmux, except for the fact that only one program is encoded, and the video quality measurement is more refined since it is based on the human visual system model compared with statistical multiplexing, which, in turn, is based on basic rate control of quantization parameter (QP) value. In order to have a more accurate video quality measurement, the CAE live system is trained offline using artificial intelligence technologies.

For VOD, CAE can be used in one pass, as done for live. This provides the highest scalability (encoding speed) but not the lowest compression ratio. Alternatively, this can be done in several passes, where each encoding parameter set is encoded in parallel and the decision is made at the end of each encoding batch. This is the technique currently used by Netflix.

TABLE 4. The savings provided by Harmonic’s EyeQ CAE technology.

Resolution	Frame Rate	Profile	Max Bitrate (CBR)	Saving (%) Balanced
1920 × 1080p	50	AVC High	6	37
1280 × 720p	50	AVC High	3.5	34
960 × 540p	25	AVC Main	1.8	31
640 × 360p	25	AVC Main	1.25	31
320 × 180p	12.5	AVC Main	0.5	39

Table 4 provides the typical savings compared with CBR encoding on HD content using Harmonic’s EyeQ CAE solution.

The overall savings compared with CBR averaged over all profiles is 34%, close to the 40% demonstrated by the Ultra-HD Forum on UHD.

In addition to bandwidth savings, CAE also offers a better QoE to where when the video is better compressed, more HD profiles can be received, and when the bitrate is low, there are fewer buffering effects.

Figure 4 represents the analytics results when comparing CBR versus Harmonic’s CAE EyeQ technology on a 4G network. The profiles used were the ones described in **Table 3**.

For more details on CAE, Harmonic has published a white paper on the subject.[15]

Delay Impact on QoE

Latency is an issue during ABR delivery, whether over-managed or unmanaged networks, and more recently, this problem was noticed during the 2018 FIFA World Cup, when viewers watching the event via OTT services discovered that the platforms were not very stable (see the section titled “Network delivery aspects for ABR delivery”). The OTT services were way behind the broadcast delivery. **Figure 5** explains the difference between a classical ABR delivery and CMAF Low Latency Chunk (LLC) delivery.

The MPEG-CMAF is a media container standard that was recently introduced to simplify the distribution of OTT at scale. MPEG-CMAF is based on fMP4 [ISO Base Media File Format (ISOBMFF)] and can be used by both MPEG-DASH and HLS delivery formats with a common encryption scheme. Indeed, cipher blocker chaining (CBC) scrambling is now supported by Apple, Microsoft, Google, and Adobe, allowing for a single scrambled media segment, even though different digital rights management systems (DRMs) are used by end-user devices. Different MPEG-DASH manifests and HLS playlists are still required, but with CMAF,

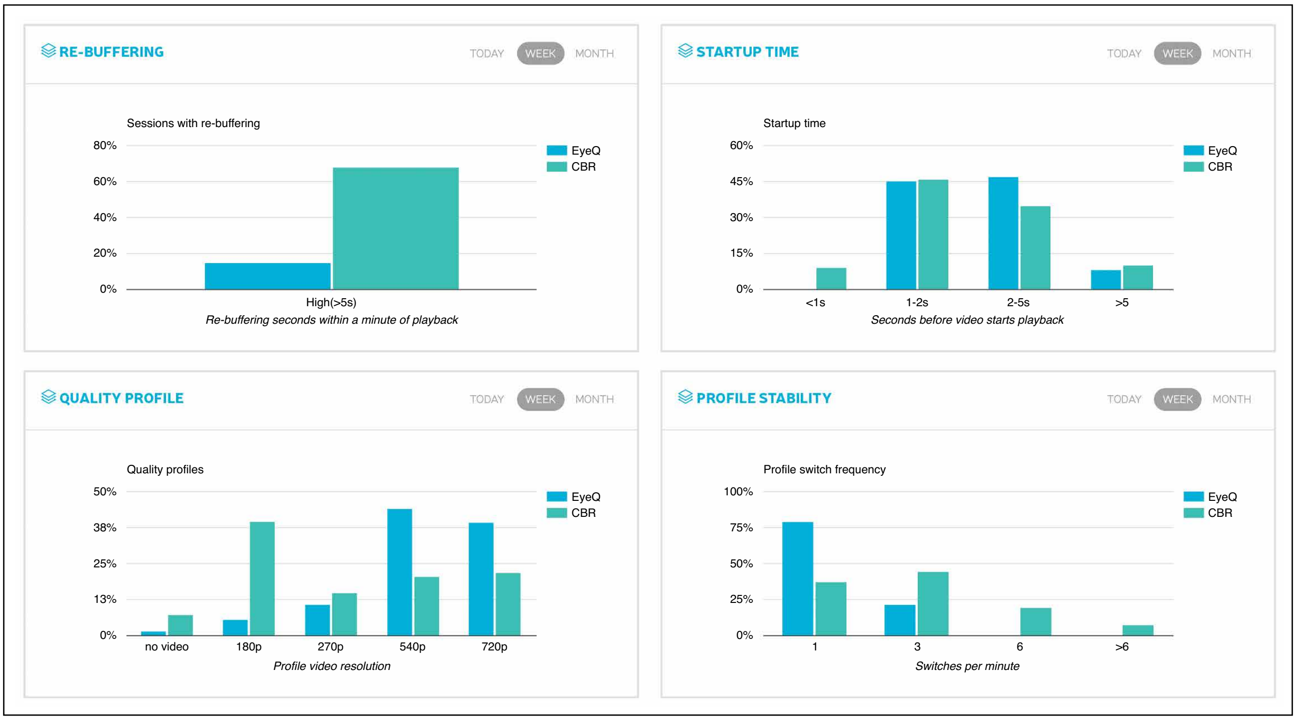

FIGURE 4. Analytics showing the benefits of CAE.

the media segment becomes common across both formats, which greatly simplifies the heavy load of the content distribution workflow.

The second major benefit of an MPEG-CMAF is the LLC option to support low latency. MPEG-CMAF LLC introduces the possibility to deliver a segment by small chunks (e.g., 200 ms) before the full segment is calculated. With CMAF LLC, data transmission is accelerated across the whole workflow, including in the decoder, which can potentially start decoding/display before a complete segment is encoded/received. MPEG CMAF LLC performs very well and can deliver end-to-end latency of 3 sec or less with a short latency encoder and an optimized DASH OTT player (as iOS 11 supports CMAF but not LLC). Of course, the HLS player can still decode the stream but may introduce an additional latency compared with an MPEG-DASH CMAF LLC player.

Harmonic has performed a variety of field tests to compare broadcast versus ABR delivery, and full reports of the tests are available.[16] **Table 5** summarizes the different delays measured during the field tests.

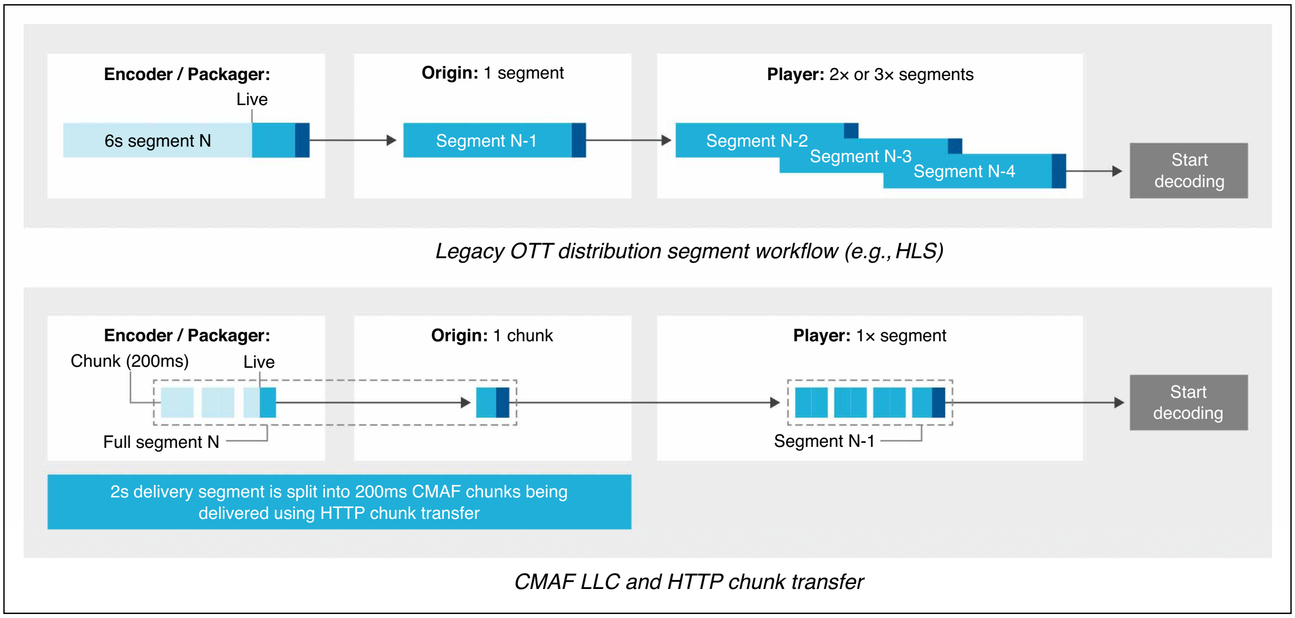

FIGURE 5. Comparing legacy OTT distribution with CMAF LLC and HTTP chunk transfer.

TABLE 5. Field trial results on low latency.

Test Conditions	Network	CDN	Network	Device	Measured Delay
On-premises	Unmanaged	Akamai	Wired	Wired	5.5 sec
			Wireless	Wireless	7.5 sec
Public cloud	Unmanaged	Akamai	Wired	Wired	7.0 sec
			Wireless	Wireless	9.5 sec

If you consider that the broadcast delay today for pay TV is around 5 sec for satellite networks, you can conclude that only the most favorable conditions (on premise/wired) can provide a delay approaching that of broadcast. Other delivery mechanisms will be between 40% and 90% additional delay. Note that if the encoder delay can be reduced, then the overall delay will be reduced with an impact on the consumed bandwidth, which today's operators are not ready to sacrifice. In the same way, a more aggressive client could save a fraction of a second with the impact being more on buffering risks, which again the operator is not ready to sacrifice.

Meanwhile, we have reduced the delay from 30–90 sec to 5–10 sec, which is a gigantic 6–9× step, or more, especially without any impact on encoding, and a minor impact on the packager, CDN, and client that all have to be upgraded with CMAF LLC. Note that if a client is only CMAF compliant without LLC support, the delay will have to be increased by a few seconds (double buffering of a segment). This could be the lazy option for operators to take until Apple releases a native CMAF LLC client.

Network Optimization

In the analytics description, this article noted that analytics have mostly been used to monitor the client behavior today. Adding analytics to the CDN and the network enables operators to gather a lot of information that will help to better understand what the chocking points in the network are.

Figure 6 describes the state-of-the-art network monitoring in today's world.

Various publications cited in this article[8,12] make a point that not all clients are equal in how they intelligently exploit ABR technology, and some of them are not even fair (always trying to get the highest bitrate on the manifest). We, therefore, believe that in severe congestion situations, it is best to guide the client and to offer only a limited manifest during the congestion period. This guidance provided to the OTT client can also be driven by business rules, giving, for example, access to top representation for premium customers and not for others during these severe network conditions.

After building a strong monitoring solution like the one described in **Fig. 6**, the next step is to build an orchestration system, which we will call the "network optimizer" that will in realtime, at the segment pace, collect all of the network analytics and will define key parameters to be applied to the network elements, including the edge cache, origin server, and encoder.

Figure 7 describes a high-level architecture for implementing a network optimizer function.

The challenge to implement such a system is that there are no standards for the analytics collection, and in order to implement this solution, the solution provider has to work closely with the operator.

Benchmarking with Netflix

Beyond the fact that Netflix is considered today to provide the best user experience for pure OTT delivery, we wanted to compare OTT service delivery for the following reasons. If a consumer has good experience with

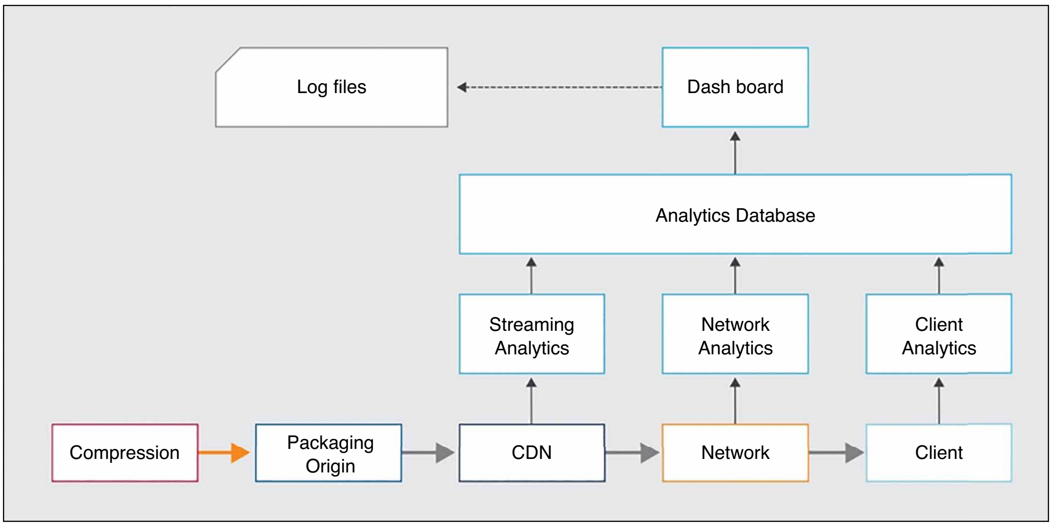

FIGURE 6. Generic network monitoring solution.

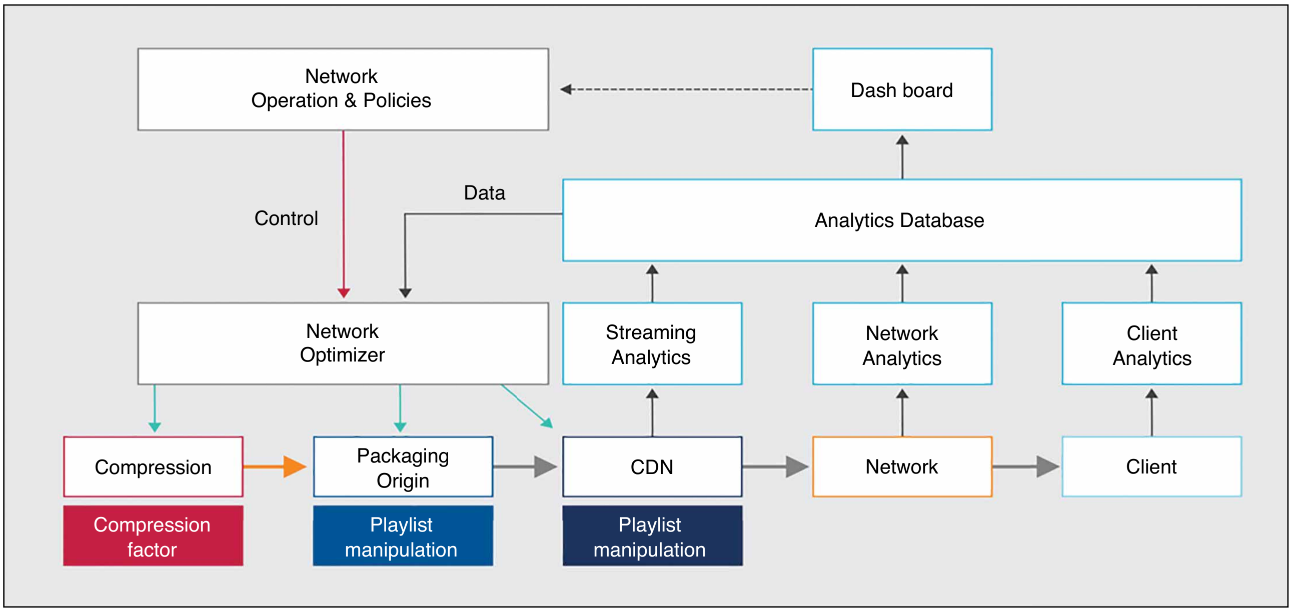

FIGURE 7. Network optimization solution.

Netflix and if an OTT provider on the same network, using similar technical parameters, such as a resolution, cannot match the Netflix QoE, we predict the service will not be successful. This section will look at all of the weapons Netflix has at its disposal.

Encoding

Netflix was the first to deploy "per tile" then "per chunk encoding" in 2015, which is the equivalent of CAE. Netflix is using HEVC only for UHD and is preparing to deploy AV1 for all of its devices in the 2019–2020 timeframe. But all of this is only for VOD asset encoding, not for live.

Edge Caching

Netflix, via its Open Connect program deployed in 2012, has deployed its own caches in ISP networks. Based on this, we can say that Netflix, when deploying Open Connect, is not an OTT service provider anymore and has a network that is close to a managed network for distribution to the home.

Traffic Prioritization

As Netflix is a pure OTT service provider, it cannot influence the QoS inside the home.

Client Optimization

Netflix has not made any publication on its client optimization technology, but Giraffic has published, in January 2018,[17] a benchmark showing that Netflix is fetching faster than regular clients. **Figure 8** provides some comparison.

Network Monitoring

Netflix has not published much on how it monitors its network, but we can expect this to be a major subject of research, as just in the U.S., it serves 58 million subscribers.

Summary

Table 6 provides a comparison between legacy OTT services, Netflix's service, and what we believe can be an ABR delivery service that can match broadcast quality.

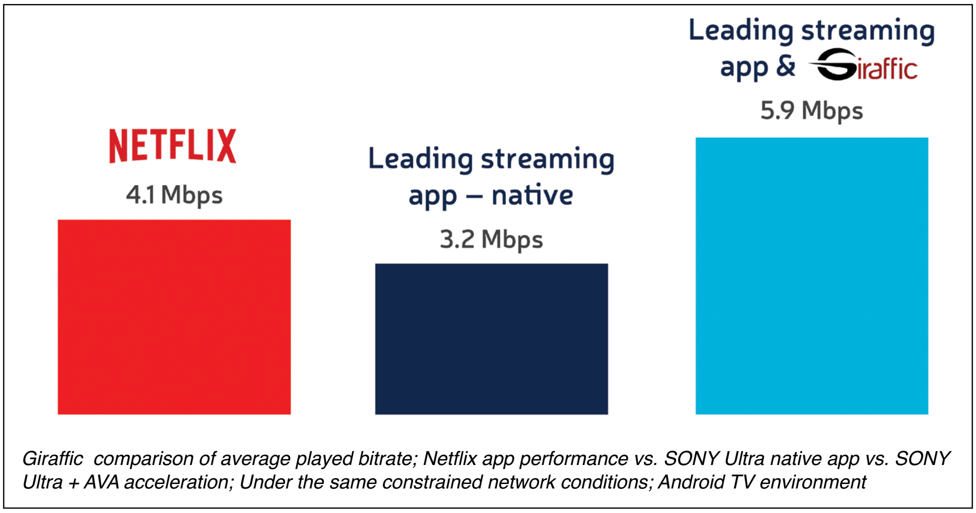

FIGURE 8. Client download comparison.

TABLE 6. Comparison of different OTT services.

Technology	Category	Standard OTT Services	Netflix	Advanced OTT Services
CAE	Encoding	No	Yes	Yes
New codec (HEVC/AV1)	Encoding	Some	Yes	Yes
CMAF LLC	Packaging (Live)	Being deployed	NA	Yes
	CDN			
	Client			
Deep caching	CDN	Some	Yes	Yes
CDN switching	CDN	Yes	Not necessary	Not necessary on managed network
Traffic prioritization	Home network	Managed networks only	No	Managed networks only
Client acceleration	Client	Some	Yes	Yes
Network optimization	Monitoring	No	Unknown	Yes

As one can see in the table, legacy OTT services are far from having all of the tools to match the QoE provided by Netflix, while the advanced OTT services can not only compete with Netflix but also provide an experience that can be close to the broadcast experience for live services.

Conclusion

This article has reviewed different network architectures that provide a better QoE for ABR delivery. Encoding, especially CAE, is key to providing the best QoE. CMAF is an essential technology to reduce the ABR delivery end-to-end latency to a level close to what broadcast offers. CDN caching is an important factor, and client acceleration should also be considered. Finally, to optimize the network resources and avoid unfair client behavior, we advise operators to deploy a network optimization technology. All of those elements make us confident that, in the very near future, an ABR delivery mechanism can be close to a broadcast delivery network on a managed network. On an unmanaged network, it would be more of a challenge, as several parameters are out of the control of the OTT service provider.

Acknowledgments

The work presented in this article would not have been possible without the support of many people at Harmonic, especially from Noam Koren and Raz Nitzan, who have pioneered the content-aware encoding and network optimization technologies, respectively, before they became a commercial reality.

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About the Author

Thierry Fautier is a vice president of video strategy at Harmonic, San Jose, CA, in charge of defining and driving the execution of the long-term strategy of Harmonic's video business. In addition, he is the current president of the Ultra-HD Forum, the global organization responsible for promoting market adoption of ultrahigh-definition (UHD) by defining industry best practices for the phased introduction of the wide set of technologies that will facilitate the next-generation viewing experience. His previous experience at Harmonic includes leadership positions in solutions marketing, where his area of responsibility covered Harmonic's major markets, including broadcast, cable, telco, direct-to-home (DTH), and over-the-top (OTT), and multiscreen initiatives. Prior to joining Harmonic, he was the vice president of marketing for Vanguard Solutions (vsofts.com), Palo Alto, CA and has held various positions at Philips Research, Limeil-Brevannes, France in research, engineering, and marketing. He was one of the primary drivers at Philips Semiconductors (now Nexperia), Caen, France and Sunnyvale, CA in the creation of MPEG technology and in the development of the first MPEG-2 set-top box system-on-chip solutions. An experienced speaker, he has presented at leading industry conferences throughout the world.

Presented at the SMPTE 2019 Annual Technical Conference & Exhibition, Los Angeles, CA, 21–24 October 2019.