SCTE ISBE

JOURNAL OF DIGITAL VIDEO

Volume 1, Number 1
January 2016

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Society of Cable Telecommunications Engineers

International Society of Broadband Experts

JOURNAL OF DIGITAL VIDEO

VOLUME 1, NUMBER 1
JANUARY 2016

Society of Cable Telecommunications Engineers, Inc.
International Society of Broadband Experts™
140 Philips Road, Exton, PA 19341-1318

JOURNAL OF
DIGITAL VIDEO

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JOURNAL OF
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Transforming the Subscriber Experience

Insights from the Front Lines of Deploying RDK & HTML5

A Technical Paper Prepared for the
Society of Cable Telecommunications Engineers
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1. Introduction

Today's consumers are increasingly drawn to compelling video services from companies like Apple, YouTube, and Netflix. To maintain their position as the content aggregator of choice, Multiple System Operators (MSOs) must create a world-class user experience for their subscribers, one which seamlessly blends live and on-demand video content with Over-the-Top (OTT) video, social media, and other applications. This requires a new vision and approach that allows for the rapid creation of immersive and deeply personalized video services that streamline content discovery, drive subscriber satisfaction, and generate new revenues. By creating this blended experience whereby subscribers access the content they want – regardless of source - MSO's brand, customer satisfaction, and revenues are elevated.

Several recent technological innovations have made the realization of this strategy possible – an approach that was in the past unachievable for MSOs. These include the adoption of Web technologies like HTML5 (HyperText Markup Language), industry initiatives like Reference Design Kit (RDK), and the introduction of cloud-based architectures. By embracing these technologies, MSOs will be in an excellent position to redefine their market position and enter an exciting new video services era.

Yet, there remain several challenges with this new paradigm, among these the most pressing are:

- Achieving world-class User Experience (UX) performance
- Migrating to Internet Protocol (IP) delivery models
- Effectively understanding and leveraging cloud based architectures
- Delivering these major projects in a timely and cost-effective manner

This paper shares key insights into real-world MSO experiences with these architectures and technologies. It presents two case studies on current operators that are creating rich and engaging subscriber experiences based on RDK and HTML5, with a blend of operator and Web-based content. The first case study will describe a MSO moving to full IP delivery with an IP Client set-top box (STB) approach; the second will examine a "hybrid" strategy by an MSO who is introducing next generation 4K/High Efficiency Video Coding (HEVC) hybrid IP STBs. Both MSOs are embracing cloud-based architectures. The paper will provide a deep understanding of how operators are leveraging today's technology breakthroughs to transform the subscribers experience and deliver real value to their subscribers.

2. Setting The Market Context

2.1. Pace of Change

Cable operators are facing unprecedented commercial and technical challenges in their video services delivery business. Competition is emerging not only from traditional sources like telecommunication and satellite operators, but also from a wide range of new and emerging competitors offering video services over the Web like Netflix, Apple, Google, MLB, Amazon, HBO and many others. In addition, consumer expectations for their video service experience from MSOs are now set by smartphone and tablet interfaces, rather than from traditional EPG grid guides. These new competitors are offering service innovation at a fast pace, fully leveraging Web technologies and cloud based architectures. The result from this competition for many MSOs is subscriber loss and churn as consumers reduce services (cord-shaving) and cancel services (cord cutting).

This perfect storm of new competitors, traditional competitors with more advanced technology platforms, and ever increasing consumer needs means that MSOs must pivot to a new service delivery paradigm. To remain competitive, they need to introduce new services at a cadence measured in months rather than years to win consumers mindshare and subscription fees.

Figure 1 shows some of the key elements being impacted by the pace of change. We'll explore these elements in more detail in the following sections of the paper.

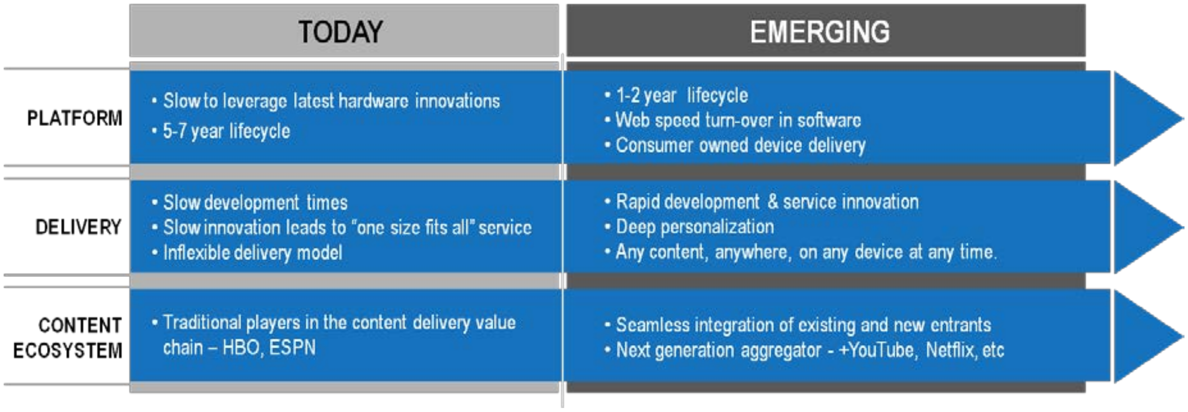

Figure 1 - Key trends for the pace of change

2.1.1. Platform

The set-top box (STB) has been the platform of choice for delivering video services to consumers since the introduction of digital cable. Historically, the introduction of a new STB is a long and complex process: project timelines are measured in years and the expectation is that the device will remain in service for at least 5 to 7 years.

However, the increasing pace of technological innovation - combined with evolving consumer expectations - has made these traditional deployment models obsolete.

With new smartphones, tablets, and smart TVs being introduced every 12 months, operators must accelerate their introduction of new STB platforms to remain competitive. These new STBs can be marketed to subscribers in a similar way as new cell phones, whose introductions are promoted events by popular media. Later on, operators should 'bite the bullet' and proactively upgrade the STBs in all subscriber homes. While this approach may be costly, it ensures operators will have the ideal platform for a highly competitive user experience in subscribers' homes. With the cost of the newest STBs falling dramatically, a more frequent STB replacement policy may make sense.

In addition, customer owned devices like smartphones, tablets and smart TVs must now be included as core elements and interfaces of video services. This means that MSOs ideally will adopt a cloud-based software approach aligned with Web technologies (and the associated pace of web innovation) to simplify and accelerate video services innovation across all devices including STBs.

2.1.2. Service Innovation: Delivery

The cable industry has driven significant innovations in video services over the years, but slow delivery of new services has remained a challenge. MSOs have devoted a lot of effort on large engineering initiatives to implement basic network and head-end components which take time to design and implement. Services delivery to consumers has seen some innovation with the advent of new services like VoD and new commercial structures like bundling, but operators are still lagging compared to their new competitors such as Netflix.

These OTT entrants to the market leverage access infrastructure that's already in place, allowing them to focus on delivering services to consumers using cloud based architectures. This approach has allowed them to innovate with compelling service enhancements like recommendation, personalization and a strong focus on a compelling overall user experience. By using Web technologies, these competitors have innovated rapidly and they continue to do so. MSOs must consider similar platforms to raise their profile and increase their pace of innovation.

2.1.3. Content Ecosystem

The explosion in consumer options for accessing their favorite content is also rapidly changing the industry. Until recently, cable operators acted as the sole aggregator for delivering video content to consumers and the number of content owners was well defined in a particular region. The market is now open to a variety of new content owners and content delivery models with some content owners (e.g. MLB.com) competing with cable operators by offering direct to consumer services using OTT technologies. New content creators and aggregators, like Netflix, have and continue to emerge challenging cable's leadership.

This market dynamic shift is causing many cable operators to undertake a strategic review of their business. Their core decision is to determine whether they should exit the video aggregation business entirely or redefine their approach and establish themselves as a next generation video aggregator. Following these strategic reviews, many operators are concluding that video services are a core driver of Average Revenue per User (ARPU). As such, they must continue to offer video services and establish market leadership, a main feature of which includes providing any content at any time at any location on any device. From this conclusion, MSO are defining a set of must-have attributes for their video aggregation services including:

1. Modern, easy to use User Interface (UI) designs for navigating and finding content
2. Blend of traditional content sources with emerging ones (e.g. Netflix, YouTube) to offer access to the widest range of content
3. Search and recommendation approaches offering a simplified and personalized experience across a broad range of content and devices

2.2. MSO Next Steps & Challenges

It's clear that MSOs need to invest to upgrade their existing video delivery platforms. To regain leadership, their video service delivery platform must contain the following characteristics:

- Significantly better basic video service
- Deliver compelling new services
- Reduce costs
- Rapidly adapt to and embrace technology advances and market changes

- Dramatically reduce the time to market for new and updated services

The cable industry has a history of innovation and has achieved many monumental steps forward over its history. They are well positioned to implement a new platform and to execute strongly. MSOs have a demonstrated ability and willingness to lead the industry and face the challenges ahead with available platforms and tools. The largest obstacle the MSOs will face is controlling their offers and the efficiency of the tools available. Let us consider these two aspects in more detail.

2.2.1. Operator Control

This aspect relates to a scenario wherein the operator is slowed from achieving business objectives by external factors over which they may have limited control. A key example of this kind of loss of control is the company delivering the STB dictating the pace of innovation for the operator.

During the initial selection process, the operator's vendor selection is often based on the best balance of price and function. However, this relationship over time can progress to a point where the delivery roadmaps no longer meet the operator needs. In this case, time to market for new features may take many months or even years and can be very expensive. This can cause frustration for the operators but there is little to be done except run through another vendor cycle and likely end up in the same situation.

2.2.2. Platform & Tool Challenges

There have been several attempts to define a STB software platform and associated tools to provide an innovation framework for the MSOs. However, the track record of these approaches has not been one of success. In North America, one such major initiative was the Open Cable Application Platform (OCAP/Tru2Way).

The intent for OCAP was to create an operating environment on STBs and other platforms (like smartTVs) onto which the operator could directly load and run applications. The promised benefits of the initiative were ideal but in reality the platform failed to meet its goals. Challenges related to standardization effort, lack of broad adoption and failure to create a broad application community led to only limited adoption with most cable operators eventually abandoning it. Similar efforts, like Multimedia Home Platform (MHP), were met with equally limited adoption.

The key takeaway from these previous attempts is that success can be measured by the volume of adoption. Volume deployment drives further implementation and widespread adoption across the industry, which leads to a dominant approach over time. For a technology initiative to be successful, it must see broad adoption by the industry and deliver on its promised benefits. Let's now turn to look at some of the key initiatives that are defining a new platform that looks set to achieve widespread adoption.

3. Key Technologies

We now have a clear view to the challenging marketplace MSOs are faced with – one where agility and innovation are critical for success, yet existing tools and approaches lack the adoption and capabilities to provide MSOs a way forward. Into this gap, several approaches have emerged that provide a new path for Multiple System Operators. Let's consider these now with an overview of the approaches.

3.1. RDK

Reference Design Kit (RDK) is an industry initiative run by an independent entity, RDK Management LLC. (RDK-M), and supported by some of the world's largest operators including Comcast, Time Warner and Liberty Global as well as over 250 licensees.

RDK offers a technology approach for video infrastructure intended to be standardized across all STBs and gateway devices. RDK does not take a traditional standards approach, rather it defines a set of software components which, when used together, deliver key STB functions. It leverages a combination of open source and other components to operate in a manner mirroring the open source community. Since its inception, RDK has been rapidly adopted with millions of STBs now deployed across North America and Europe.

RDK's advantages can be broken down into two broad domains:

1. RDK separates hardware decisions from software decisions and provides a common abstraction layer for the hardware across different Original Equipment Manufacturers (OEMs) and SOC) vendors. This approach permits the operator to deliver new hardware platforms more rapidly and at lower cost than using previous models. It also gives the operator more choice in commercial negotiations, which usually drives down costs.

2. RDK solely focuses on the infrastructure layer and relies on Web technologies and 3rd party application developers to provide the application layer. This approach allows for delivery service agility and delivery velocity not possible using previous standards approaches such as OCAP. This will be described more fully in the next section.

While RDK is relatively early in its lifecycle, its success to date has been built on the volume of adoption by MSOs and the active and enthusiastic community that has arisen around it. In fact, all major OEM and SOC vendors offering solutions to cable operators are able to provide RDK-based solutions. Community contributions from both MSOs and suppliers are accelerating its roadmap and capabilities. RDK is formal enough to offer a consistent abstraction, while flexible enough to permit operators and their integrators to extend and optimize it to fully match their needs. Proprietary solutions are still available, but it is becoming clear that they will be unable to maintain the same pace of innovation as RDK over time.

The RDK community is growing as IPTV operators also adopt it and realize the same benefits offered by a common hardware abstraction layer for IP services delivery. In fact, full IP services delivery is a direction cable operators are embracing, and RDK is an important ingredient to achieve it.

Finally, RDK is driven by operators and suppliers implementing solutions today. This ensures a pragmatic focus within the community to the benefit of all members. Further, the license structure is set up such that operators can innovate freely in the application layer – operators have complete control over how their services are offered to their consumers.

In summary, RDK allows MSOs to separate software and hardware decision making, which drives down costs. It supports the use of Web technologies for applications which provides unprecedented flexibility and agility. With the volume adoption of RDK, it is moving at a pace unheard of in previous initiatives and this will likely support its broad adoption.

3.2. Web Technologies

Web technologies are a term used to describe a broad set of technologies used to implement applications and services delivered over the Internet. It covers technologies ranging from the presentation of graphics on through to networking technologies.

The importance of Web technologies to operators is based on their extensive adoption and the pace of innovation this creates. The key emerging competitors - including Google, Netflix, Apple and even content owners like HBO - are able to directly access consumers by embracing these technologies.

3.2.1. Characteristics of Web Technologies and Web Approaches

The delivery of applications and services over the internet is very different from the manner by which cable operators have traditionally delivered their services. The Web uses a community driven approach and leverages several technologies which work in harmony and are adaptable for the best solution – if one approach does not work well for an application then another is selected. It is also characterized by large aggregation– both of people and devices – using services from the Web or the cloud. This implies architectures which are massively scalable.

Web architectures are distinguished by their volume adoption and open approaches. This results in an exceptionally high innovation rate with contributions from across the globe and a strong synergy between technology and business. This synergy creates a reciprocal cycle where new technology advances opens new business opportunities and business ideas drive technology advances.

As discussed earlier, approaches where cable operators have tried to define and drive their own standards - like OCAP and/or MHP - have never been able to compete with the massive participation of the Web. Leveraging Web technologies permits operators to bring the pace of Web innovation to their business. Additionally, since the new competitors are leveraging these same technologies, it makes sense for cable to level the play field and embrace the same approaches.

4. Practical Deployment Approaches

This section will review real world examples of the MSOs using RDK and Web technologies for the delivery of services including both IP and Quadrature Amplitude Modulation (QAM)/IP hybrid solutions.

4.1. Architectural Framework

There are multiple ways to architect STB client software, but a common approach is shown in Figure 2.

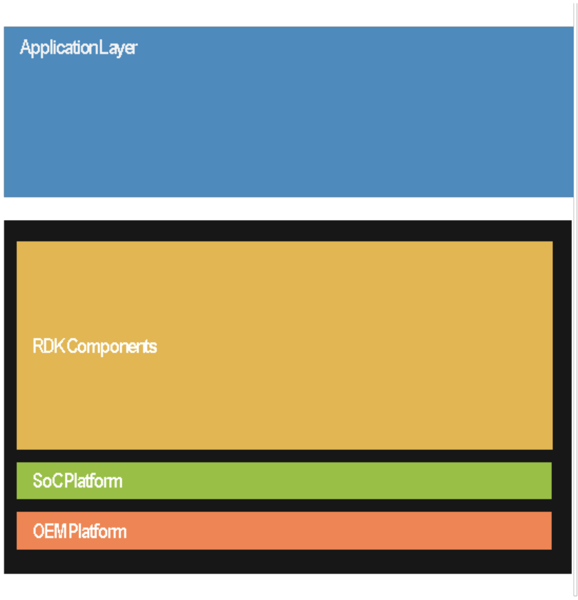

Figure 2 - Generalized STB client software architecture

This approach is used by RDK: the components at the bottom layers reflect the RDK - specific components from the OEM, the SOC vendor and from the RDK-M code repository (RDK Components). Above these is an application layer where the operator delivers core video applications and can blend in other features including Web applications like YouTube.

4.2. RDK and RDK Extensions

Real world experience using RDK has confirmed many of the key values of this approach. Some essential metrics are reflected in Table 1 that illustrates the engineering time savings being realized on multiple STB project activities today.

Table 1 - Summary of key RDK benefits

Function	Pre RDK	Post RDK	Saving
Base port between SOCs	3-4 weeks	5 days	75%
Base port between STBs	2-3 mths	10 days	83%
Hardening video pipeline	2 mths	10 days	75%
CAS integration (after first time)	3-6 mths	2-3mths	50%
Channel change time (2-3secs)	1.5 secs	350-450ms	70%
Application layer porting	2 mths	10 days	75%

The measured benefits of RDK fall into several categories:

1. Porting between SOCs and STBs is considerably simplified. The base port is clearly a first step in a typical project and real world experience is showing significant reduction in porting time and complexity.

2. Hardening key components like the video pipeline can take some time on the first project. The large benefit is that once this is completed under RDK by a client developer, it will be supported across future ports with only testing required to validate the new platform.

3. Conditional Access System (CAS) support is typically challenging as it impacts not only the integration but also the software architecture. Experiences across a number of leading CAS vendors - including Nagra and Cisco - creates a secure software architecture which is much more easily ported between STBs and customers using different CAS vendors.

4. Access to source code provided by RDK permits optimization of essential functions. One specific example is support for rapid channel change using spare tuners to allow pre-tune to adjacent channels. The initial implementation saw a channel change time significantly reduced from 2-3 seconds down to 1.5 seconds within the RDK community. By instrumenting and optimizing the code for processing, the client system integrator is capable of achieving further time reductions with a channel change time improved to 350-450ms.

5. Finally, the application layer is separate and built on top of the RDK layer. The application layer encompasses several key capabilities including the UI as well as integration to the operator back office for authentication, subscription information and metadata. Since RDK is consistent across platforms, porting the application layer is faster and easier than in more traditional STB software architectures.

Over the past number of years, the community has expanded the capabilities of RDK considerably. However, operators will typically still need to add some extensions to create a platform fully meeting their requirements. Some of the typical extensions are:

1. Protocol support (e.g. IP multicast, HTTP Live Streaming (HLS), Dynamic Adaptive Streaming over HTTP (DASH))
2. CAS/DRM integration
3. Monitoring agents (e.g. Agama)
4. Regional standards (e.g. HbbTV in Europe and BML in Japan)

4.3. Implementing an Exceptional UX

The architectural diagram outlined earlier shows the application layer as a single block. For best practices, the design of this layer needs to be carefully optimized to ensure exceptional UX performance. In fact, some early adopters of HTML5 and Web technologies built solutions using protocols typical to the personal computer (PC) environment. This led to a flexible and agile solution, but one with unacceptably slow performance. There are two main reasons for this outcome:

- Differences between PC and STB hardware – a STB is a specialized device optimized for the delivery of video and audio services. This needs to be understood and reflected in the implementation approaches.

- UX response times – where HTML5 is used on a PC it is may be acceptable for Web page rendering to take some seconds for a response. These times are simply not acceptable for MSO subscribers – on a STB the user expects the response to key pressed on the remote control to be almost instantaneous. This needs to be understood and reflected in the implementation approach.

The next sections address some of the key activities involved in creating an exceptional UX using HTML5 and Web technologies.

4.3.1. Optimizing the UX

To optimize STB user experience, there are several parameters which need to be optimized including:

- Fast video: optimization of HTML5 video integration (intelligent algorithms for buffering, video management and media player integration) is required so video performance is very fast and startup/switching time from one video to the next is instantaneous
- Full screen animation measurement: must support full screen HD animation with excellent performance which is a challenge beyond getting superior performance on a section of the screen (i.e., ¼ screen, ½ screen, or a portion of the screen)
- 2D and 3D animation support: one has to deliver fast performance with an elegant UX that incorporates both 2D and 3D objects
- Mixed object animation: a real world requirement is the ability to support animation and updating graphics, texts and multiple HTML overlays (opaque and transparent) simultaneously

- No pause or stutter: it is easy to achieve peak frames per second (FPS) performance although visual distraction like pausing or stuttering is distracting to the user and results in poor user experience. The solution needs to focus on a fast peak FPS and also ensure that even the lowest frame rate is still high enough to ensure no pause, stuttering, etc. in the visual experience
- Key response time and overload: instant key response, with no overloading (run on after the user stops pressing) or visual pixel response
- Asynchronous loading: the application framework must balance data caching with direct data retrieval from the cloud to provide the performance typically associated with native applications. The user expectation is to near-instantaneous display of the UX with fast navigation which relies on an asynchronous loading approach for some parts of the UX
- Caching: modern UIs have very large amounts of metadata including descriptions, posters, tags, cast and crew. If data is always retrieved from the cloud then the performance is slow. Targeted caching creates exceptional performance while still operating within the available resources on the STB
- This means that the user action is decoupled as much as possible from the retrieval of data from the server delivering screens that are populated instantly as the user navigates

4.3.2. UX Customization

Being able to differentiate your solution from that of your competitors is an essential business principle. Accordingly, UX customization generates great interest from operators. The user interface is an operator's 'face' or brand to their subscribers. Thus everyone, from the engineering group to the product group to the CEO, are often is involved in its design. There are approaches and frameworks where a standard UX is offered with some limited flexibility to customize and modify. Typically, operators start down this path and then realize they want to implement a more customized UI than is supported with the standard UX provided.

Despite the vastly different desires for design and interactions requested by operators, there are many common elements which need to be implemented independent of the look and feel:

- Graphical elements including grids and poster strips
- Graphical transitions
- UX presentation and view management including:
    - Rights management for 3rd party applications
    - View lifecycle management (Apps, Dialogues, Pop-ups)
    - Focus, events & navigation management (seamless navigation between applications, menu always on)
- Metadata back-office aggregation, data format optimization, texture caching for high user performance

Through careful separation of the aspects related to look and feel from the common aspects that build these user experiences, up to 70% of the implementation can be reused across very different UX designs. This permits an approach where a high degree of customization is possible without incurring the high cost and risk of a typical custom design project. Additionally, the performance of the UX is consistently delivered since the performance optimization is mostly already available in the common elements.

4.4. Implementing Different Deployment Architectures

Cable operators are broadly in the process of transitioning from QAM to IP and from CPE-based functionality to cloud-based functionality. However, not all operators are at the same point of this transition and this is evidenced by the range of solutions currently being implemented. Espial is working with cable operators who are delivering:

- A 100% IP solution where there is a transport gateway terminating the QAM-based transport and the distribution to the STB is all IP. This operator is also fully embracing cloud based approaches including Video on Demand, Time shift TV (Catch-up and restart) and network DVR (nDVR). This approach makes the STB much simpler and the delivery of services to multi-screen devices inside or outside the home as well as to STBs only limited by software policies applied in the cloud

- A cable / IP hybrid where IP connectivity can be assumed. QAM-based transport is used for broadcast and a mix of QAM/ Real Time Streaming Protocol (RTSP) and IP/Adaptive Bit Rate (ABR) is used for on demand services. In this case, metadata is delivered over IP. As in the previous solution, all devices are served directly from the cloud

- A cable / IP hybrid where IP connectivity is not always available. In this case, the QAM path is fully utilized for delivering both media and metadata and multi-screen devices are supported for live TV by in home streaming from the STB/gateway

The architecture proposed across these operators, all of which leverage RDK and HTML5 / Web technologies, fits well into all of these deployment models. The approach also supports evolution as networks are upgraded, IP connectivity becomes confirmed and cloud services are implemented, then the client can be upgraded to take advantage of these approaches.

4.5. Implementing Applications

At a high level there are three broad classes of application which may run on a STB:

1. Core video application or master application
2. Operator defined applications
3. Third party applications

The core video application is the most important one on the STB as it provides the primary access point for consumers to access content and offers the visible brand of the operator to the consumer. The services offered by this application have moved far beyond early implementations which offered grid guides only to provide an advanced interface across a wide range of services.

The core video application is now rich in graphics and descriptive information, simple to navigate and highly personalized to the users. A wide range of services is supported including live TV, on-demand TV/movies, catch-up/start-over TV and DVR/nDVR. The goal is to provide consumers with the fastest and easiest way to access relevant and interesting content so they are not motivated to seek other sources.

One area where innovation can occur is through the blending of a wide variety of applications into the service. The STB is a specialized device for delivering content to consumers – this is the central approach to consider when looking at applications delivery. The smart TV manufacturers have shown the two most popular applications by far in most markets are Netflix and YouTube – both of which are content centric.

Operator defined applications are those built by the operator. These applications, which the operator has total control over their implementation and testing, can be considered trusted applications. Examples of these may be customer self service applications, widget applications like weather or specialty content applications.

Third party applications are those built by third parties and over which the operator has limited control. These applications can be included in the overall service offer to ensure the consumer has access to the largest range of content possible. These applications are typically considered as untrusted as the operator has no control over their behavior.

The core video application is typically launched using special buttons on the remote control unit but operator and third party applications can be integrated in a number of ways. The software solution architecture described in this paper supports the following approaches to application stores and launching for access to operator and third party applications:

1) The UX can integrate applications which can be launched by the user in context of the user navigation. For example, IMDb can be launched in context of details on an asset.

2) The UX can offer the user seamless navigation to present a list of available applications read from a Web server hosted in the operator data-centre. Each application has a manifest defining its name, icon and security status (trusted or un-trusted). The applications are presented to the user by icon and run when selected.

3) Application stores (e.g. Accedo or Metrological) can be launched and the applications run. APIs offering applications access to STB functionality like local store can be provided.

To support this blended approach, a number of architectural elements need to be considered:

1. Navigation – user interaction must be simple and intuitive. A clear understanding of context and position must always be available and, in a world of many applications, the familiar home button must be always easily available.

2. Security – applications may be built by the operator or by third parties over whom the operator has no control. Security containers must be available which can be used to constrain usage of RAM and other resources on the STB and also to control access to APIs available on the STB.

3. Flexibility and agility – the UX needs to be designed in a manner which is inherently flexible and extensible to permit applications to be added and removed over time as the operator's business evolves.

4.6. An Optimized Application Layer Architecture

Tying together the key insights from the previous sections of the paper, the ideal architecture to support the application layer is reflected in the Figure 3 below.

The STB Client based on HTML5 and RDK in Figure 3 is designed to deliver exceptional application performance across all elements of the user experience. It achieves this with a layered architecture and data-driven application engine that ensures quick and responsive user interaction. The software layers include the Application Framework and UX Framework, which are designed to ensure fast time to market and reduced risks on application/UX performance.

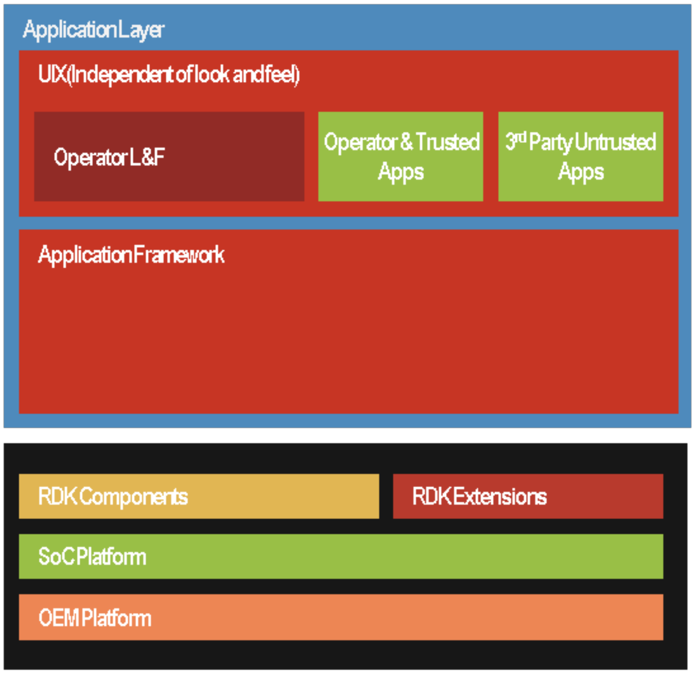

Figure 3 - STB client architecture showing a break-down of the application layer

4.6.1. UX Framework

The UX framework provides a high performance and secure library of pre-built HTML5 and Javascript core video apps, operators and Web apps. It provides intelligence to ensure seamless animations, transitions and navigation across the core video, operator and Web apps in the UX. This approach allows for the rapid creation of operators defined UI designs, cutting down the development cycle by 70% compared to traditional UI design approaches.

4.6.2. Application Framework

The application framework is an advanced application engine that integrates into back-office systems - the video and hardware layers of the STB - as well as the user experience layer for a superior multi-applications performance. It provides powerful intelligence to handle highly optimized caching and acceleration for extensive sets of rich and detailed program metadata. As well, it includes capabilities such as application security, Web application media extensions and advanced application memory management to ensure high performance and seamless interaction across the UX.

4.6.3. RDK and RDK Extensions

This infrastructure layer ensures the delivery of a complete solution including the relevant RDK components, and all integration services required to support RDK, with extensions for regional, media, CAS/DRM, and IGMP, as well as operator specific functions.

4.7. Summary of Implementation Experience

This section describes some of the MSO delivery projects Espial has been working on leveraging the architectures and approaches described in this paper.

4.7.1. MSO Migrating To Full IP/Cloud Architecture

This customer is a cable operator migrating to a 100% IP infrastructure model and leveraging a cloud based architecture. Features of this approach include:

- Broadcast services delivered over IP Multicast
- On demand services delivered over HLS, a shared approach with multi-screen devices
- DVR provided using network DVR approach
- Catch-up and restart services
- Companion / multi-screen interaction
- The operator is deploying a blend of applications from Web, specialist third party and their own developments

4.7.2. MSO Implementing QAM/IP Hybrid/Cloud architecture

This customer is a cable operator migrating over time towards an IP infrastructure model and leveraging a cloud based architecture. Features of this approach include:

- Broadcast services delivered over QAM
- On demand services delivered over QAM and DASH
- Catch-up and restart services
- Companion / multi-screen interaction

- DVR provided using network DVR approach
- The operator is deploying a blend of applications from the Web and specialist third parties

4.7.3. MSO Implementing QAM/IP Hybrid/Gateway Architecture

This customer is a cable operator migrating over time towards an IP infrastructure model and leveraging a gateway based approach. Features of this approach include:

- Broadcast services delivered over QAM with streaming to multi-screen devices in the home from the gateway
- On demand services delivered over HLS, a shared approach with multi-screen devices
- Companion / multi-screen interaction
- DVR provided using local DVR approach
- Deploying limited applications from Web

4.7.4. A New Delivery Model – DevOps

The architectures and approaches described in this paper can be used to advance the delivery model even further by adopting a DevOps approach. This approach incorporates AGILE software development methods, used by many engineering organizations, to extend into the Operations domain associated with the production delivery of services. The approach can be used by operators to test services in small groups or regions easily before updating based on feedback and deploying broadly.

The operators Espial has been working with are not yet taking this step but it is certainly possible based on the technology methods being deployed.

5. Conclusion

MSOs are facing unprecedented competition which is driving a greater pace of change than ever seen across the cable industry. Cable has always actively embraced new technologies. Many approaches, though, have missed the market on their promised benefits for a variety of reasons. Recently, though this has changed with the development and adoption of RDK and Web technologies. Their success is driven by volume adoption and is driving very fast innovation.

This pace of change is causing a rapid evolution in operator business models, yet, it remains critical to retain video services as a core element of the overall MSO service mix. By adopting the right technology platform, MSOs can retain their position as the primary video services aggregator. Transition is always challenging and the signs are very positive that cable is successfully navigating the path to maintain their video leadership. These radical changes will ripple through the cable industry and permit it to retain its position as the premier group for the delivery of video services to consumers.

The technology approaches described in this paper, such as RDK, are being deployed today by leading cable operators across the world. The cases covered illustrated examples of each at different points in their transition and the benefits they are quickly realizing. The most exciting insight is that their technology platform will permit them to continue to successfully innovate to maintain their leadership through a market that will continue to see unprecedented competition.

6. Abbreviations

ABR	Adaptive bit rate
ARPU	Average revenue per user
BML	Broadcast Markup Language
CAS	Conditional Access System
CPE	Customer-premises equipment
DASH	Dynamic Adaptive Streaming over HTTP
DRM	Digital rights management
DevOps	Development and operations
EPG	Electronic Program Guide
FPS	Frames Per second
HbbTV	Hybrid broadcast broadband TV
HD	high definition
HEVC	High Efficiency Video Coding
HLS	HTTP Live Streaming
HTML5	HyperText Markup Language
IGMP	Internet Group Management Protocol
IP	Internet Protocol
IPTV	Internet Protocol television
MSO	Multiple System Operator
MHP	Multimedia Home Platform
nDVR	network Personal Video Recorder
OCAP	OpenCable Application Platform
OEM	Original equipment manufacturer
OTT	Over-the-Top content
QAM	Quadrature Amplitude Modulation
RDK	Reference Design Kit
RDK-M	Reference Design Kit Management
RTSP	Real Time Streaming Protocol
SCTE	Society of Cable Telecommunications Engineers
SOC	System on a Chip
STB	Set-top Box
SVOD	Subscription Video on Demand
UX	User eXperience
UI	User Interface
VOD	Video on Demand

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Access Architecture Redefined

Using Wi-Fi to Deliver Next Generation Services

A Technical Paper Prepared for the
Society of Cable Telecommunications Engineers
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1. Introduction

Cable subscribers are looking for an easy and simple network to reach their content. We are no longer defined by a time and space constraint to consume what information we are after. As part of this paradigm shift, Wi-Fi is a growing opportunity for cable operators (Operators). The demarcation of our data service has already changed significantly given industry headwinds and tailwinds. This paper outlines the methodology and framework required for a redefined access architecture that will enable Operators to deliver next generation services to our subscribers while offering new monetization opportunities.

2. Current state of Wi-Fi Access Architectures

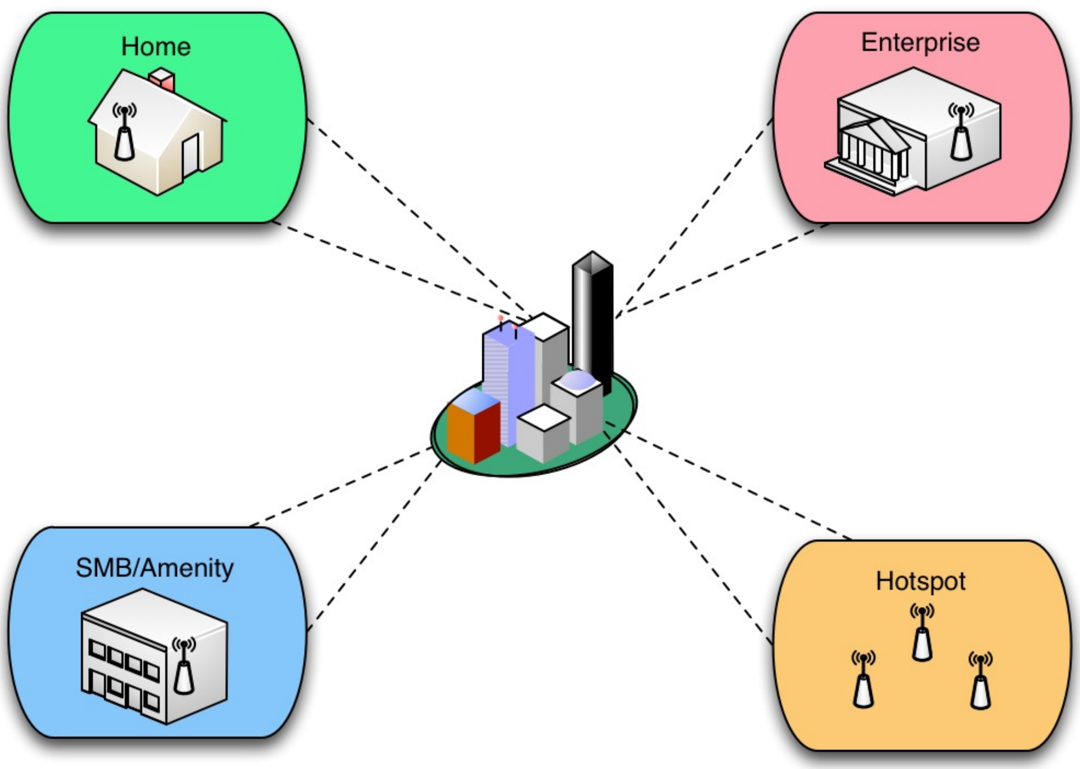

Figure 1

2.1. The Home

The home network in Figure 1 has been a problematic offering for both the consumer and service provider for some time. The consumer is in many cases required to set up and manage their own network, often with little knowledge of best practices. Once initially set up, often keeping devices connected and in an ideal state can be problematic, intermittent and unexplainable to the end users. As technology has increased and compensated for some of these consumer woes with the number of devices connecting, the essential bandwidth for a device to operate has increased and the Wi-Fi environment itself has become more complicated, introducing additional challenges. With these frustrations not always being linked to

Wi-Fi or the home network, these often have become the problem of the service provider. While removing the home router during troubleshooting has become common practice to get around these complications, it still drives customer care calls and increases end user frustrations. As the demarcation has changed and, due to increased costs and obstacles beyond our control such as the overwhelming task of assisting with troubleshooting a variety of devices and challenging environmental hurdles, service providers are cautiously hesitant to embrace this change.

As the devices themselves have simplified, so has the consumer's perspective of a "good experience" – the consumer wants to attach and consume with ease in the age of bring your own device (BYOD). As service providers, this has been leading to a trend of a managed home offering, where the router is integrated into a semi-managed gateway. While this brings about some level of additional support to the customer, it also brings about the next wave in a fundamental shift of our business.

2.2. The Hotspot

The hotspot in Figure 1 has existed for years and whether it is at the local coffee shop or at the park, the experience is often inconsistent and used opportunistically at best. Businesses have leveraged Wi-Fi as an opportunity to draw in customers through consistently delivering connectivity at all of their locations. Personally, we have leveraged these locations on numerous accounts over the years when connectivity was required and cellular just wouldn't cut it. While the experience is not always consistent, the value of a hotspot to the consumer is not easily questioned any longer. As we have learned from cellular voice, just good enough frequently is just that, just good enough to meet the user's needs.

For the past several years in an effort to add value to their customers, many cable operators have been deploying hotspots in targeted metro areas to increase the value proposition to their customers. These have been largely considered successful and we have seen those footprints with their corresponding usage grow. They offer connectivity for existing subscribers and partner networks, and in the case of Cable Wi-Fi, have a footprint of over 400,000 access points and official partnerships between 5 MSOs. The value proposition today is an invisible extension of the home "pipe" at no charge, providing access on the go. This concept is also proliferating into the home network by adding an extension of the hotspot into a secondary service set identifier (SSID) on managed gateways. The addition of this concept known as Home as a Hotspot (HaaHS) allows roaming connectivity access in more locations for our subscribers, growing our hotspot footprint.

2.3. The Small Business (SMB) and Amenity

As hotspots in Figure 1 have become an ever-increasing draw for consumers, businesses have seen Wi-Fi go from a value-added service aimed at attracting customers, to a mandatory amenity at their establishments in order to continue business. From a service provider perspective, this has allowed us to offer new packages to small businesses and hospitalities effectively extending our data offering to now also include a simple to manage Wi-Fi service, both for employees and for their customers. Customized SSIDs and captive portal pages allow the business to have a custom branded offering and experience. Some cable operators quickly leveraged these opportunities to expand their own hotspot footprint as well, whether through simply adding a product offering that layered in the hotspot SSID or have chosen to deploy their own branded hotspot offering as the product to meet the business demands. Support models for these services have been as varied as the offerings themselves. In some cases, the business itself is the first line of support and serves as a proxy while, in others, the service provider supports any end user connectivity difficulties directly.

2.4. The Enterprise

The enterprise offering in Figure 1 has largely been untouched, however the managed Wi-Fi offering still remains an attractive one as IT services continue to become outsourced to on-demand companies, which have left an opportunity for the service provider to extend their data offering to include managed services of the Wi-Fi infrastructure assets installed on the customer premise. The nature of these networks and the customers' desire to keep access controlled and secure has kept these networks from becoming advantageous to merge into the Operators' broader hotspot footprint. However, the demarcation and support hurdles previously outlined still exist, at an even higher service level agreement (SLA) and with less tolerance for a real or perceived less than desirable end-user experience.

2.5. The Opportunity

Wi-Fi is the common access medium across the majority of our lines of business. The access experience and the shifting demarcation is a pain point for both the Operator and the end user. Embracing the demarcation change allows the Operator to position the offering to be the entire hotspot footprint, while offering a similar experience outside of the primary customer premise. An opportunity exists to strategically deploy a platform with access and services that will improve our offering in both the access and content delivery markets. See Figure 2.

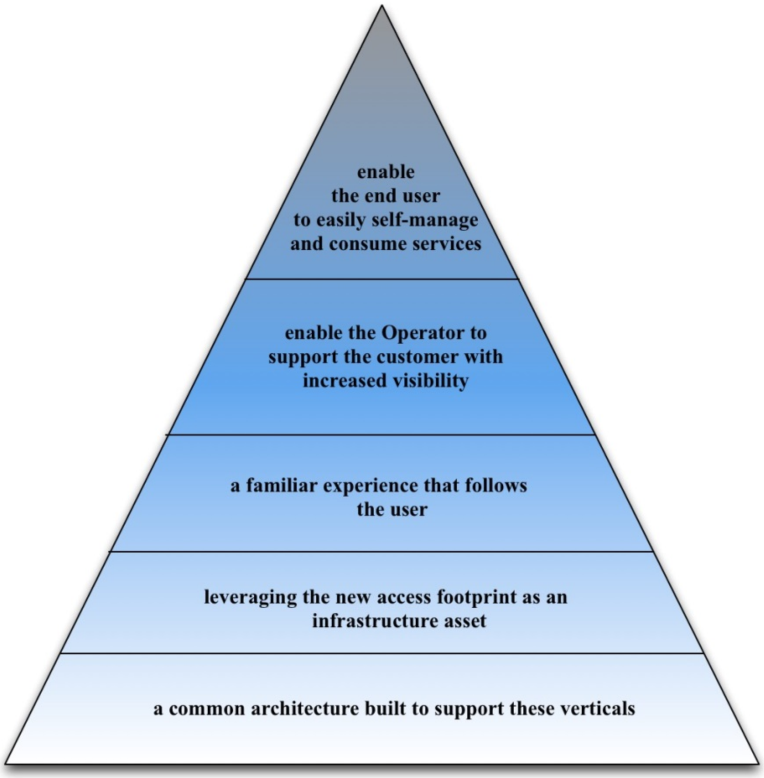

Figure 2

3. Future Services

3.1. Core Service Offerings

There are a variety of advanced service offerings that should be considered for deployment across these verticals and product offerings. Ideally, these would be aimed at allowing the primary users to limit, control or have insight into sub-users and devices, while equally allowing users to have greater and more simplified access to more content and services. The virtual customer premise device (vCPE) model outlined within this document combined with service function chaining (SFC) and/or software defined networks (SDN) via a policy charge and control function (PCRF) would allow a very dynamic subset of any of the following services to be applied with relative ease. These examples may be used equally for residential and business, government, school and medical applications.

- **Independent user/device policy control** – the ability to apply access policies such as time of day (ToD) or bandwidth consumption limitations and quality of service (QoS) priorities to a set of users or devices.

- **Content filtering** – the ability to restrict content for a set of users or devices, ideally limiting specific pre-defined categories, such as adult material or other content.

- **Device protection** – the ability detect and identify malicious threats on specific devices.

- **Personal/Family cloud storage** (with layer 2 discovery) – this could include integration with native backup clients within device operating systems.

- **Cloud media storage -** with layer 2 discovery and Digital Living Network Alliance (DLNA) capability.

- **User and device visibility** – Deep Packet Inspectors (DPI) could be integrated to identify and trend top-sites for given users/devices that the “Household Admin” opted in. A parent could obtain reports on the Internet activity of their children, even seeing requests that were blocked in content filtering or illegal file downloads.

- **Usage reporting** – Reports could be made available utilizing PCRF accounting data to show user and device usage statistics, possibly even showing the equivalent cost of cellular data fees and associated cost savings.

3.2. Beyond Wi-Fi

These same policies and functions could apply to wired ports and wired devices within the same architecture. Whether those are wired ports in a home, business, or hospitality, the user experience could easily be the same through similar encapsulation methods for wired access methodologies. This is a foundational access requirement due to on-site wired assets such as printers and LAN storage, but it can also be packaged as another offering of the same solution. This lays the foundation for a new set of core services that can easily be individually attached to create dynamic services bundles per account, user or device, and are completely extensible across all verticals and access mediums.

3.3. The Extended Home

With users accessing a virtual network and associated services across a Wi-Fi connection, the home experience could easily map to the entire hotspot footprint. The same policies that are applied by a "Household Admin" within the home, could apply to the entire hotspot footprint. As children go to their friend's house down the street that is also a subscriber of the same service provider, the same restrictions (or a defined subset) could be applied. Reports on insight and usage could provide the same information for the broader footprint, and even provide breakdowns of location. Cloud storage could be accessed outside of the home. Furthermore, "Smart Home Devices" could be accessed securely from any Wi-Fi access location within the hotspot footprint. These devices could include security systems, thermostats, local storage devices and even printers. When off network, a user could even potentially access all of the same services and dashboard through an over-the-top (OTT) app.

3.4. Benefits of a Converged Access Methodology

Delivering a variety of services from common, converged access architecture offers benefits to strategic, capital and operational objectives across an Operator's lines of business and streamlines workflow processes and procedures. In addition, it also offers new ways of increasing penetration in multiple market segments by leveraging the foundational architecture to deliver new value added services. Consider these few use cases:

- **E-Rate Digital Divide Initiative** – a managed Wi-Fi school or government contract could include a number of consumer electronics devices pre-provisioned with services for lower-income students. These devices could obtain Child Internet Protection Act (CIPA) compliant Internet access across the entire Operator's footprint through pre-configured PCRF policies and could be "always on" even across suspended data plans (as the suspension could occur to the account and associated devices, not the circuit itself). Local businesses utilizing the Operator's service could display window stickers advertising their participation in Digital Divide initiatives.

- **Mobile Workforce** – businesses with a mobile workforce could add roaming services for their employees allowing them to ditch their geographical bounds, while still allowing the same policies, restrictions and shared content to apply across the broader footprint.

- **Traveling Residential User -** a subscriber that is travelling and staying at a hotel within the same Operator's national footprint could obtain the same speeds, access all of their same services and maintain the exact user experience as if they were at home. Child devices could still have the same restrictions applied on the road, possibly even having logic to always apply the most restricted policy between the device and the location.

3.5. Partnerships

The resulting benefit to our subscribers of providing a converged Wi-Fi access media and corresponding products is a strong value proposition within each of our respective footprints. That value proposition only strengthens as multiple-system operators (MSOs) work together to collaborate and bring together a united roaming footprint of our Wi-Fi services. As technologies such as Passpoint 2.0 gain mass adoption, our ability to maintain our individual brands while offering our subscribers a much stronger overall network presence and experience will become vital.

4. Future State

4.1. Next Generation Enabling Wi-Fi Architecture Overview

The proposed future state for the converged Wi-Fi architecture outlined within this paper is shown Figure 3:

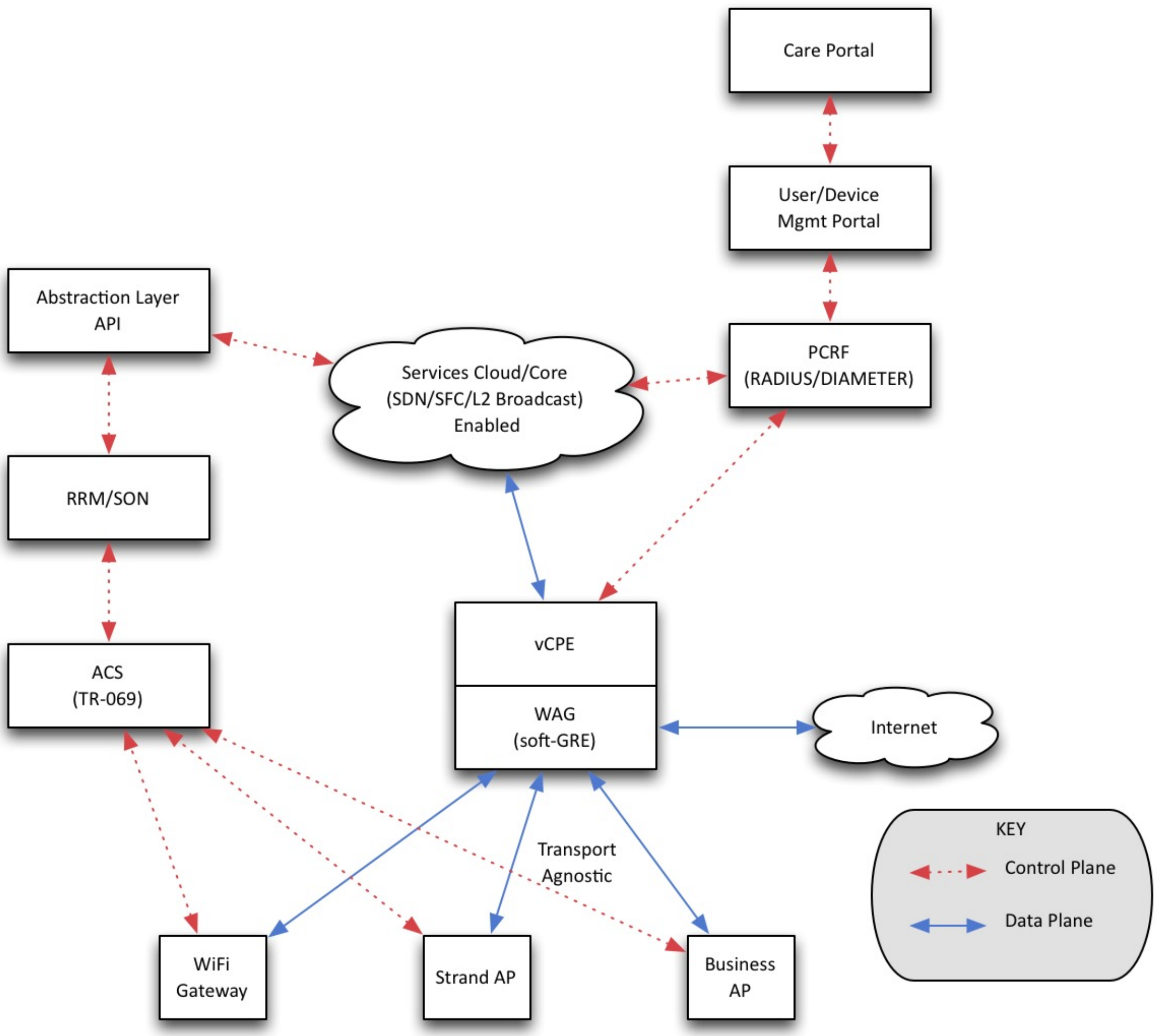

Figure 3

4.2. Key Components

4.2.1. *Wi-Fi Access Gateway*

The Wi-Fi Access Gateway (WAG) is at the center of the next generation Wi-Fi architecture. The core functions are termination of soft-GRE capable access points (APs) and policy enforcement including layer 2 northbound stitching to vCPE functional component. The Wi-Fi access gateway (WAG) also serves as a mobility anchor point to allow roaming within the Operator's Wi-Fi hotspot network. It is important to note that the WAG and vCPE functional boxes are shown immediately next to each other since some implementations have these functions within the same physical component. A high level functional overview of some of the possible requirements surrounding a WAG is shown in Figure 4.

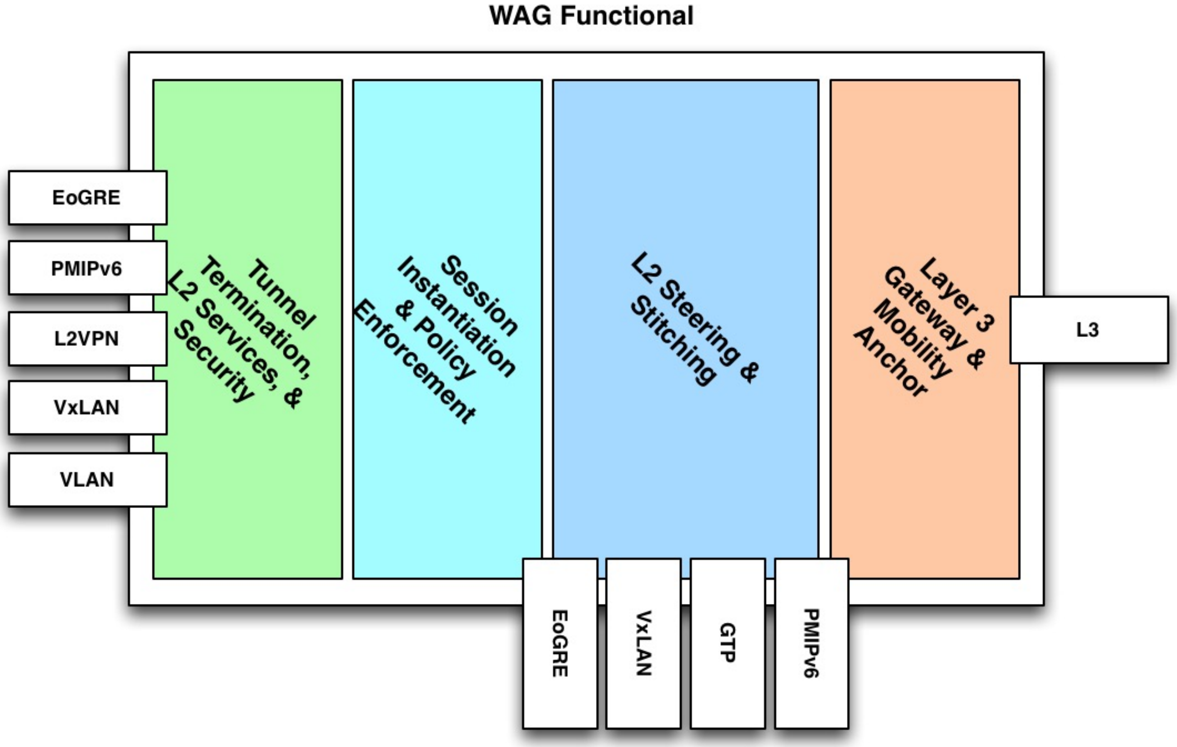

Figure 4

4.2.2. *vCPE*

To address the support and visibility hurdles, as well as to increase the managed Wi-Fi experience for the end-user, the concept of virtual customer premise equipment (vCPE) has had growing interest. While the exact details of what this entails vary by implementation and implementer, the concept is to take the intelligence and functions of the customer premise equipment (CPE) out of the physical CPE, and move it into a virtual CPE construct in the cloud. Fundamentally, this allows the Operators greater control and visibility into the CPE functions itself, while still allowing the customer to perceive no significant change in their experience or network. With the customer care agent having more visibility into the CPE itself, including even at the layer 2 and consumer device level, they can have more troubleshooting tools at their disposal and ultimately resolve many end-user device issues without a truck roll. Also, while moving it into a virtual construct, the vCPE can easily be manipulated over time, either through CPE firmware upgrades, user-interface (UI) updates, etc. without being limited by the physical hardware on-site.

Purely from a functional perspective, this could be a great opportunity to redefine the concept of a home network. CPE functions such as Wi-Fi configuration management, dynamic host configuration protocol (DHCP), network address translation (NAT), port forwarding, and firewalls, are no longer required at the edge, or to be managed by the user in the same means as before. Many of the functions that the common CPE perform today were implemented for reasons that may no longer apply in a virtual home network, managed by the Operator. DHCP can potentially move onto carrier class enterprise systems. NAT can potentially move into carrier grade NAT implementations. IPv6 can be rolled out with ease, and the entire architecture could be based on IPv6 only deployed infrastructure. Proxy and firewall functions may still exist, however the ways in which a user/device can implement these could potentially change drastically. With vCPE, the Operators have the ability at implementation to redesign the home network based on architecture of today, with the requirements of today. Of course a symbiotic balance of "do no harm" must also be maintained as the slightest initial changes could begin to cause confusion and unease in the customer and ultimately drive operational expenses through customer care calls.

4.2.3. Services Cloud/Core

Figure 5 represents our cloud and data center infrastructure. The ability to quickly roll out services, dynamically chaining them together on an individual user/device specific policy is heavily reliant on SFC and SDN technologies, while possibly leveraging Network Function Virtualization (NFV) as well. Some potential technologies to be included here are:

- Content Filtering
- Distributed denial of service (DDoS) and Threat Prevention
- Deep Packet Inspectors (DPI)
- Cloud Storage
- L2 Broadcast services:
    - DLNA
    - Universal plug and play (UPnP)
    - Internet of things (IoT)/Smart Home use cases

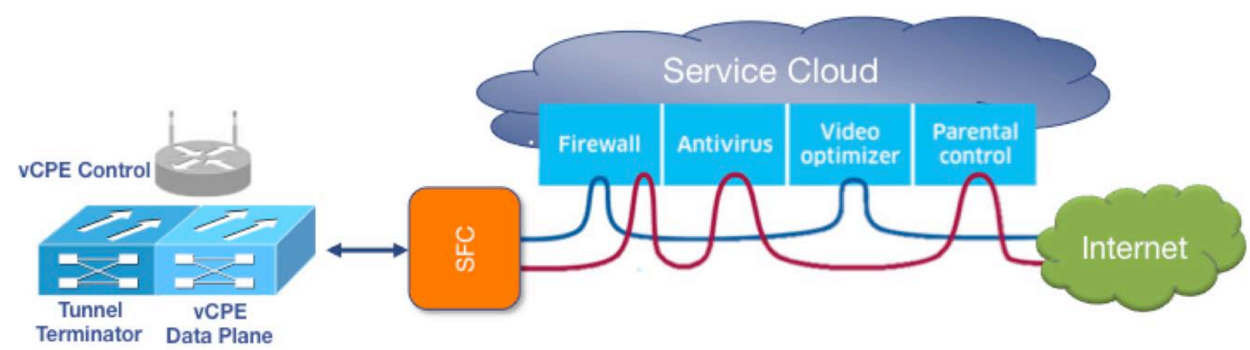

Figure 5

4.2.4. Policy and Charging Rules Function

The PCRF is responsible for granting access and distributing policies to be enforced at the WAG and vCPE components. It may also require supplying policy to individual services within the Services Cloud/Core, SDN and SFC components. This functional component needs to be highly customizable while remaining robust and scalable. This is a critical component in a successful architecture outlined within this paper and each Operator will likely have distinct requirements for this component based on back-end systems, business rules and partnerships.

4.2.5. User/Device Management Portal

With the introduction of Wi-Fi hotspots and a Wi-Fi core platform, Operators are already authenticating devices associated to an account within legacy backend systems. This has created the requirements for many Operators to create a user interface portal where customers can manipulate and manage User IDs associated to devices, all within an active account. This presents a unique challenge to many Operators who have previously only been required to manage accounts. A hierarchy much like the below is required to facilitate a UI for subscribers to manage their devices. This hierarchy also lays the foundation for a Wi-Fi only user. See Figure 6.

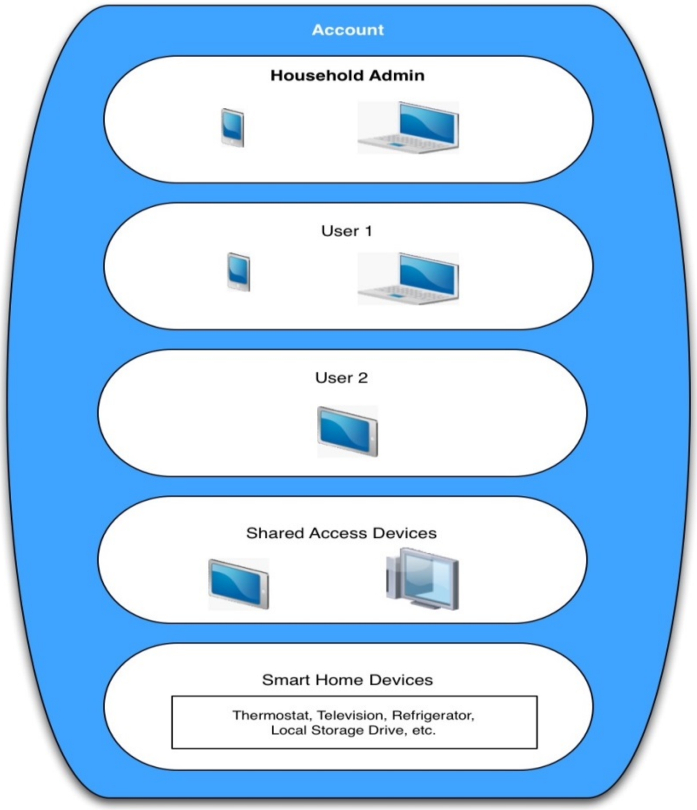

Figure 6

4.2.6. RRM/SON and ACS

With the demarcation changing, and the challenges Operators will face with complex environments in the home, multiple dwelling units (MDUs) and overall hotspot footprint, an optimization and control plane function for radio resources is imperative. The radio resource management (RRM)/self optimizing networks (SON) and auto configuration servers (ACS) components serve to pull configurations and statistics from the radio edge, calculate optimizations necessary and push the necessary optimized configurations to the APs. These functions will aid in ensuring that our subscribers have a desirable experience when leveraging our hotspot networks. As the services we deploy become more complex and begin to include video and voice, the level of optimization required by our network will increase as well.

5. Conclusion

Looking at our current state related to Wi-Fi, the industry trends and delivery obstacles we have faced in the past, and where the industry and consumer is heading, it is clear that our access networks are on the cusp of an evolution. As Operator's hotspot networks continue to grow and mature, we will have an opportunity to evolve our data services to this new architecture and mindset of a unified access delivery network. A strategic underlying architecture equivalent or similar to the one outlined within this document can enable Operator's to deliver new services and empower our customers and communities, while driving new revenue and growth opportunities. Providing our subscribers more access, an enabled cloud delivering new services and content, while strategically placing our access network at the core of content delivery and device enablement; creating one perceived network that is enabled like never before.

6. Abbreviations

ACS	auto configuration server
AP	access point
API	application programming interface
BYOD	bring your own device
CIPA	Child Internet Protection Act
CPE	customer premise equipment
DDoS	distributed denial of service
DHCP	dynamic host configuration protocol
DLNA	Digital Living Network Alliance
DPI	deep packet inspection
GRE	generic routing encapsulation
HaaHS	home as a hotspot
IoT	internet of things
MDU	multi-dwelling unit
MSO	multiple-service operator
NAT	network address translation
OTT	over the top
PCRF	policy charge and control function
QoS	quality of service
RRM	radio resource management
SDN	software defined networks

SFC	service function chaining
SLA	service level agreement
SMB	small business
SON	self optimizing networks
SSID	service set identifier
ToD	time of day
UI	user interface
UPnP	universal plug and play
vCPE	virtual customer premise equipment
WAG	Wi-Fi access gateway

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Deploying Next Generation Media Technologies with Applied Constraints

A Technical Paper Prepared for the
Society of Cable Telecommunications Engineers
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1. Introduction

Once a standard is created, it is often assumed that a technology can be deployed, but that is not the case. It takes hard work by groups of individuals negotiating items that can affect capability, cost, integration, and interoperability. Usually, for a standard, such as video coding to be effective, it needs to address a specific application (e.g., linear broadcast) or asset of applications (e.g., Internet Protocol Television - IPTV, Video on Demand - VOD, Cloud Digital Video Recorder - cDVR) before it can be used.

This paper describes the role of application or industry groups for creating guidelines that enable the adoption of a technology into an industry.It uses specific examples from several groups that write application or industry constraints, such as the Society of Cable Telecommunications Engineers - SCTE; Dynamic Adaptive Streaming over HTTP Industry Forum - DASH-IF; and CableLabs. In particular, issues are examined that revolve around next generation technologies, including High Efficiency Video Coding - HEVC, Internet Protocol Television - IPTV, Ultra High Definition Television - UHDTV, and High Dynamic Range – HDR. Some issues that will be discussed include: 1) creating testable operating points, 2) preventing "collisions," 3) what to do about corner cases, and 4) not "rebuilding the bridge." This paper intends to give the reader more of an understanding about why these types of organizations exist and why interaction with them will be extremely valuable as next generation cable technologies come online.

2. Content

2.1. Adopting a Standard

Media technology standards help to define the formats of video and/or audio and their synchronization, as a stream or file, for some aspect of the content media chain (see Figure 1.) This could be defining a color gamut (e.g., BT.2020), a file format for intermediates/Visual Effects (VFX)(e.g., Digital Picture Exchange - DPX, video coding compression standards for distribution (e.g., Motion Picture Experts Group – MPEG, High Efficiency Video Coding – HEVC), defining a video signal over a connector (e.g., High Definition Multimedia Interface– HDMI), signaling for how video is displayed on a screen (e.g., Active Format Descriptor - AFD), or even on a browser (e.g., Hypertext Markup Language - HTML5). Some groups defining these standards across the content media chain are the Society of Motion Pictures and Television Engineers – SMPTE, the International Telecommunications Union's Recommendations – ITU-R, the Moving Pictures Experts Group – MPEG, the ITU Telecommunication Standardization Sector – ITU-T, the Internet Engineering Task Force – IETF, the World Wide Web Consortium - W3C, the High Definition Multimedia Interface group – HDMI, and the Consumer Electronics Association – CEA.

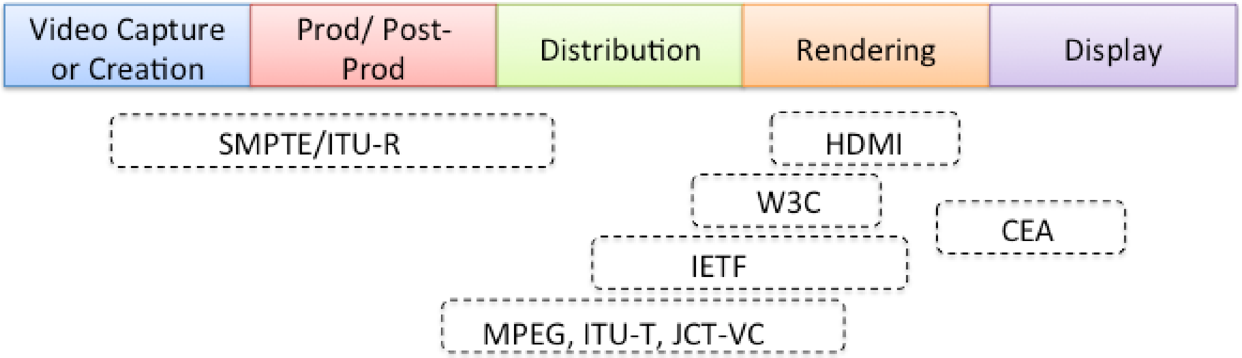

Figure 1 - Standards Organizations in the Media Content Chain

Adoption of a standard indicates that industries are able to find applications and uses for the technology such that services and products can be created. A standard in and of itself may not meet this criterion, because many standards are designed to work across multiple industries. For instance, an MPEG video can be used in broadcast, but it can also be used in video conferencing, Digital Versatile Disc – DVD, archiving, security, low bit rate space communications, etc. Each video stream may be useable in that particular application space, but may not be valid in another application space. Additionally, it may not encompass the complete media experience that may involve aspects beyond video and audio, such as closed captioning, emergency alerts, ratings, splicing, encryption, and distributed transmissions. With the advent of personal devices, mobility and the ability to access content from the Internet, consumer video services need to achieve a consistent experience across different transports and platforms – despite the fact that the underlying carriage format may change from broadcast transmission on managed networks to the home to http delivered unicasts on unmanaged networks to a mobile device. The ability to maintain consistent end-to-end (E2E) video services in next generation services is critical and will require guidelines to be designed around the candidate standard and the targeted application space.

2.2. Application Standardization Bodies

Application standardization bodies create guidelines for standards in a defined application space. The combination of some of these standards (e.g., video and closed captioning) can form a market with useable services and reasonable costs, which attract competitive and interoperable devices. The process of adopting a standard can be shown in Figure 2, which shows how the MPEG standards are adapted to IP transport through specifications from the Internet Engineering Task Force – IETF, and further adapted to different applications by way of application standard bodies such as Society of Cable Telecommunications Engineers – SCTE, Blue-ray Disc Association – BDA, and DASH-IF. These guidelines are only effective, however, if the application space is “well-defined.” This can be expressed in terms of functionality, but it can also include other factors, such as regionalism (SCTE, Digital Video Broadcasting – DVB, and the Association of Radio Industries and Businesses – ARIB), closed end systems (e.g. Blu-Ray), and devices (hardware, software, complexity, and storage.)

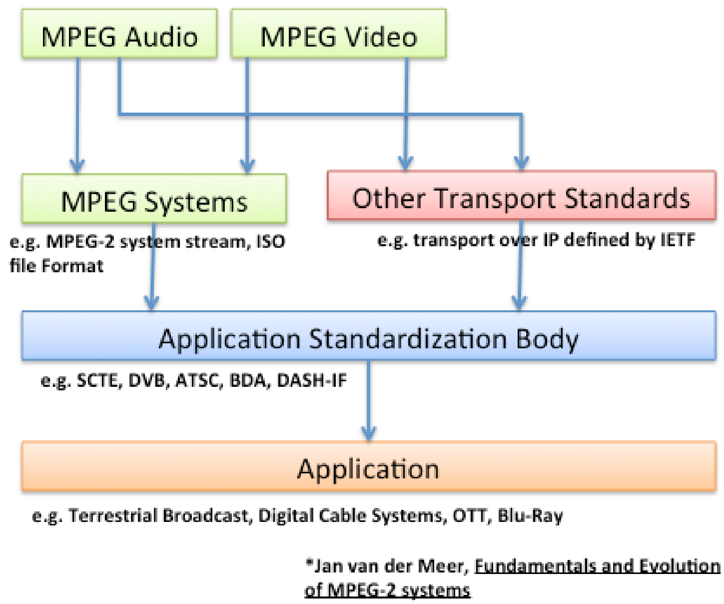

Figure 2 - Application Adoption of MPEG Standard

Application guidelines were created to reduce costs and increase interoperability between different types of products in the ecosystem (e.g., transcoder and decoding device; ad conditioning systems and splicers.) It should, however, avoid specifying a single implementation of the technology, because that could lead to limitations in future improvements to the technology in the application space. In more recent developments, application specifications are being used to create more consistent E2E service experiences between different transforms, platforms, and applications. The rest of this paper will describe how application guidelines are being used to implement these tasks, citing several examples concerning the adoption and development of next generation technologies (HEVC, DASH, High Dynamic Range – HDR.)

2.3. Reducing Costs

An industry will not adopt a standard just because of exciting new features. For example, light field technologies have the ability to refocus a scene to different objects in a picture, and right now, novelty cameras are being sold with these types of technologies -- but in terms of video applications for light field technologies, a market potential still needs to be realized before standards and application guidance can be developed. A key component in cost optimizations is enabling a realistic market where products can be developed and reliable services can be delivered. Creating application-specific guidelines should aid in reducing costs and create compliancy or testability to a standard.

2.3.1. Examples of Reducing Ambiguity/Complexity

In the recently completed work on HEVC constraints for cable networks (SCTE 215-1, SCTE 215-2), there was a discussion about how to unambiguously signal a `fixed-frame-rate-type` stream (mode for the majority of content) from a low-delay-type stream. In most cases, fixed frame rate is the most common use for broadcast and VOD applications, and requires regularly-timed flushing of pictures from the Decoded Picture Buffer (DPB.) Alternatively, low-delay streams are used for less common applications such as music channels (really a slow still image change every 30-60 seconds along with a video track) and trick modes (where the frames used do not require a separate file), and require a different decoder behavior, in that a picture is not flushed from the DPB until the next picture arrives.

In the Advanced Video Coding – AVC case in SCTE 128-1, a single flag (`fixed_frame_rate_flag`) in the Video Useable Information – VUI could be used to signal a fixed frame rate or a low delay stream. This made it easy for decoder products to look for a flag, to understand which behavior mode to operate their DPBs in. In HEVC, these indicators got pushed down into the Hypothetical Reference Decoder – HRD parameters and could thus put a stream in a mode where both fix frame and low delay could be simultaneously and inadvertently indicated in the stream. So what was a simple flag used for AVC decoding now became a more complex issue that used more bits for HEVC decoding.

To maintain a similar simplicity to indicate fixed frame rate and to prevent a stream from being simultaneously signaled as fixed frame mode and low delay, SCTE 215-1 put in guidelines that simply indicate the fixed frame rate mode, using the `vui_hrd_parameters_present_flag` as the indicator of fixed frame rate (with parameters in the HRD parameter set being inferred.) At the same time, the guidelines mandated that fixed frame rate and low delay could not both exist in the same stream by constraining the HRD parameters such that fixed frame rate and low delay could not exist at the same time. This reduces costs because it provides a simplistic and clear way, in the stream, to distinguish fixed frame rate from low delay. In turn, that helps product design for both encoders and decoders. It also reduces costs, by lowering the amount of processing that the decoder needs to do for the most common case of fixed frame rate.

Other examples in SCTE 215 or SCTE 214 that clear up ambiguity are:

- Defining the placement in the stream of Prefix SEIs (Supplemental Enhancement Information, a new concept in HEVC) and Suffix SEIs as happening before and after the first VCL NAL of the access unit (SCTE 215 allows the decoder to waste less processing checking for these conditions)
- Requiring all access units (AUs) to start with an Access Unit Delimiter – AUD (SCTE 215 makes it easier for the decoder to parse and process the stream)
- Mandating Picture Timing SEI to be present in each AU (SCTE 215 allows the decoder to know if it is working on interlaced or progressive material and reduces the amount of processing conditions it needs to check)
- Use of an `AssetIdentifier` to identify multi-period assets (SCTE 214 clearly identifies main content from promotions or advertising in the stream)
- Use of `Role` = “main” in an `adaptationSet` (SCTE 214 clearly identifies the video component in a period that can be use as the default media component)

2.3.2. Examples of Reducing Corner Cases

To be compliant to a standard, the products being used must be able to handle all possible configurations according to “Profile” (which is a collection or subset of tools in a standard), “Levels” (which are categories of processing within a profile) and “Tier,” a new concept in HEVC, which involves dual categories of bit processing within a profile. Reducing the number of allowable configurations reduces costs because products do not have to design in resources to account for these seldom used types of streams.

An example of this is the restrictions on the use of `AdaptationSets` of DASH MPDs (Media Presentation Description) in SCTE 214-1 (MPEG DASH for IP-Based Cable Services), a body of work coming out of the DVS Working Group 7 / WG7 (DASH/ Adaptive Streaming technologies) of the SCTE. In this document, the Representations within the `AdaptationSets` (and represented by a series of Single Program Transport Streams – SPTSs) are restricted to having the same codec and aspect ratio, and each has a unique stream bandwidth. This reduces the number of corner cases that the client decoder needs to anticipate when it switches between segments. For instance, a single decoder does not have expect to switch from a segment with a 16:9 aspect ratio to another segment that is 21:9. The decoder costs goes up (or quality does down) when having to scale between aspect ratios that are close in size. Additionally, a single decoder does not have to anticipate switching from AVC to HEVC between segments, which would cause a disruption in the playout of the video -- because a single decoder would have to reset its buffer. Lastly, the unique bandwidth limitation on representations in an `adaptationSet` reduces the corner case of resolution change with bitstream switching. These three constraints help to reduce the number of variables in decoding an adaptive-streaming-delivered video.

Other examples that reduce corner cases are:

- Elimination of 24hr picture from a broadcast video stream (SCTE 215 reduces resource demands on the decoder that are really meant for video conferencing applications)
- Elimination of dangling fields (both SCTE 128 and SCTE 215 reduce processor complexity in handling of interlaced material)
- Restrictions on leading pictures on an HEVC Random Access Picture – RAP with `nal_unit_type` of Trail_R (SCTE 215- reduces processor resources and complexity)
- Defining a NAL Unit Order for HEVC Random Access Points (SCTE 215- reduces processor checking and parsing process)
- Restrictions on `nal_unit_types` (SCTE 215 eliminates `nal_unit_types` such as TSAs and STSAs that wouldn't be expected in the video stream anyway)
- Restricting the PIDs for Representations of a single `AdaptationSet` to be the same across SPTSs (SCTE 214 reduces the complexity costs by being able to handle each representation in the same way with the same rules)

2.3.3. Examples of Improving Interoperability

Designing interoperability through interface points between different products that work in the same environment reduces costs by allowing a choice between products of the same functionality. For the video streaming case, this could be interoperability between encoders and decoders, transcoders and packagers, and server and clients through a set of stream conformance points.

In SCTE 215 (HEVC constraints), a table of stream conformance points was created in the appendix, mapping specific resolutions and frame rates for UHDTV1 to HDTV to SDTV (see Table 1). Each of these rows was created to form a test operating point for a video streaming system. The criterion for an encoder is whether it can create these streams at each of these points. The criterion for the decoder is whether it can process these streams (or a subset of them) at these points. Being able to use these test operating points ensures a base level of operation in these services -- even when products are swapped out with a different company's products. Conformance companies create a set of streams based on these tables, which help to certify products and significantly reduce the amount of interruptions (corner cases) that can happen in the system.

Table 1 - Resolution and Format Constraint Points

Vertical Size (lines)	Horizontal Size (pixels)	aspect_ ratio_idc	Display Aspect Ratio	Supported Frame Rates (P-progressive i-interlaced)	Production Format
2160	3840	1	16:9	P-1,2,3,6,7,8	UHDTV1
1080	1920	1	16:9	P-1,2,3,6,7,8,9, 10 I- 4,5	HDTV
1080	1440	14	16:9	P-1,2,3,6,7,8,9, 10 I- 4,5	HDTV
720	1280	1	16:9	P-1,2,3,6,7,8,9, 10	HDTV
480	720	3	4:3	P-1,2,3,6 I- 4,5	SDTV
480	720	5	16:9	P-1,2,3,6 I- 4,5	SDTV
480	704	3	4:3	P-1,2,3,6 I- 4,5	SDTV
480	704	5	16:9	P-1,2,3,6 I- 4,5	SDTV
480	640	1	4:3	P-1,2,3,6 I- 4,5	SDTV

In adaptive streaming, interoperability occurs between transcoders and packagers/fragmentors in terms of how the packager breaks down the transcoder's continuous stream into segments. An application guideline that helps out in this is the Cablelabs Encoder Boundary Point (EBP) Specification, which specifies a timing & signaling structure that determines the different ways by which a packager can segment the transcoded stream (see Figure 3). As a result, packagers can be tested by how they handle streams with the EBP structure in it (see Figure 4). Similarly, transcoders can be tested by how they place the EBP structure in the stream, and how it conditions the stream for segmentation and ad insertion.

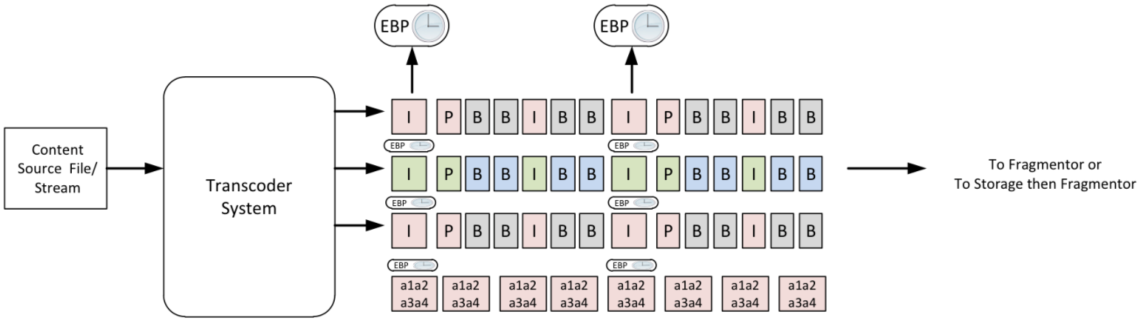

Figure 3 - Creating Transcoded EBP Streams

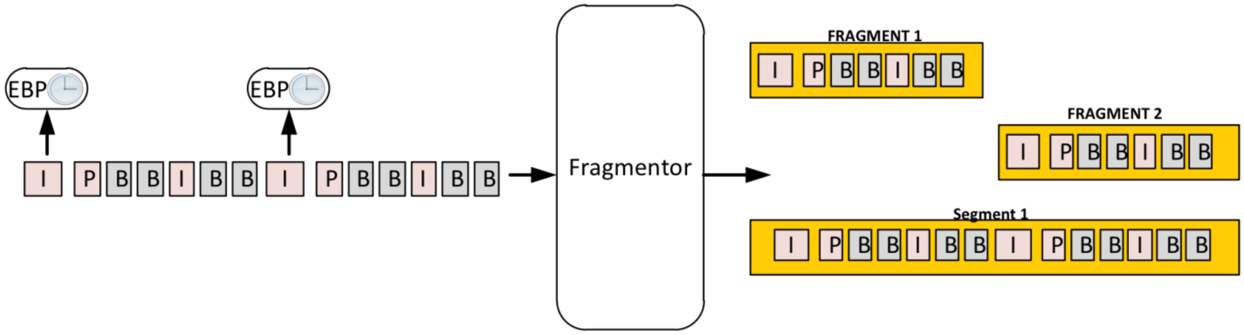

Figure 4 - Packaging of EBP Streams

2.4. Creating a Consistent Service Experience

Application guidelines also benefit standards adoption by reflecting the needs of the services in the application space. These service needs can cover types of restrictions based on specific combinations of standards required for the application. An example of this which is in SCTE 54 is the restriction of a single video elementary stream in an MPEG stream. Recently, with the use of tablets and cell phones, services are expanding onto multiple content formats and delivery platforms (DASH, MPEG2-TS, Multicast, Unicast, cable, fiber, wireless) -- and still customers expect a consistent quality of experience, even given that it's being delivered across multiple platforms across devices and transports. Early implementations tried to establish a separate workflow that duplicated the service across each platform, but as volume scaled up in each platform, the maintenance of each workflow grew more complicated due to feature replication; for instance, replicating mechanisms like ad insertion, closed captioning, wall clock time, encryption, presentation metadata, etc. As scale increases, it becomes harder to maintain each individual workflow, and thus ensuring service consistency becomes more difficult and complex. An alternative strategy is to identify and to convert information from one workflow to another at strategic points in the network. In this case, constraints are needed to allow conversion to take place from one platform to the other. Often, several application guidelines need to work in conjunction to allow for an E2E service feature to exist meaningfully.

2.4.1. Examples of Unifying a Service Feature

Closed captioning was originally put into analog video broadcasts on line 21 of the Vertical Blanking Interval – VBI using different guidelines, which are EIA-608, Teletext for National Television Standards Committee – NTSC, Phase Alternation Line - PAL, and Sequential Color with Memory - SECAM. When broadcast moved from analog to digital video and with MPEG-2 adoption, closed captioning needed to be embedded in the digital video stream using the picture user data construct carried by each frame of the MPEG-2 structure. Each application group used several overlapping specifications to capture this (e.g., SCTE 20, ETSI EN 301 775, A/53-ATSC). When AVC services were being developed in 2004, individuals from the DVB, ATSC, and the SCTE proactively converged upon a single solution (in order not to keep rebuilding the bridge) to carry closed captioning in the AVC digital video streams. This was an SEI construct in each of their documents along with a captioning descriptor that was signaled in the Program Map Table – PMT. The SCTE version of this is described in SCTE 128 (AVC Constraints.) This same construct ended up also being used in HEVC as described in SCTE 215, since the concept of SEI and NAL structures still exist in HEVC. In adaptive streaming, closed captioning services are converging to pass the SEI captioning payloads to the client application, and ultimately the decoders, with the signaling component for closed captioning being carried in the manifest (see DVS 214). There is still a lack of a standard approach of sending closed captioning information between different components, such as transferring to an HDMI interface, but the gap is narrowing.

Examples of potential areas for unifying service features:

- Carriage and signaling of accessibility features (descriptive video services, intelligible audio)
- Carriage and signaling of commentary audio tracks
- Identification of Mix of Audio Channels
- Signaling of HDR content
- Constraints on carriage of dynamic metadata
- Multicasting between networks, servers, and gateways
- Carriage of wall clock timing of live content from producer to distributor to client

2.4.2. Examples of Conversion Constraints

Conversion constraints are a new area in the development of application guidelines, and deal with specifying how information is sent between components. This basically involves constraining each component side such that information can be unambiguously passed through. If the constraints are done properly, the formats can be converted bi-directionally.

An example of this is the work being done in SCTE 214, which applies constraints to assist converting between the DASH MPEG-TS MPD format and ISO-BMFF MPD format (see Figure 5.) Here, the `adaptationSets` for an MPEG-TS profile would need to be converted to `adapatationSets` for a file format profile, but a constraint of restricting the `adaptationSet` to a single media component would be needed. Track headers in file format reflect the Packet Identifier – PID numbers of the MPEG elementary streams. Program Map Table – PMT, Program Association Table - PAT and Program Clock Reference – PCR information is carried in each segment. Signaling for closed captioning is carried through the accessibility descriptor to allow for user agents at the browser to identify closed captioning languages without digging into the stream and thus reduces bring up time at the user interface. Similarly, an audio descriptor for the audio tracks of descriptive video or enhanced-audio- intelligibility is standardized through the role descriptor.

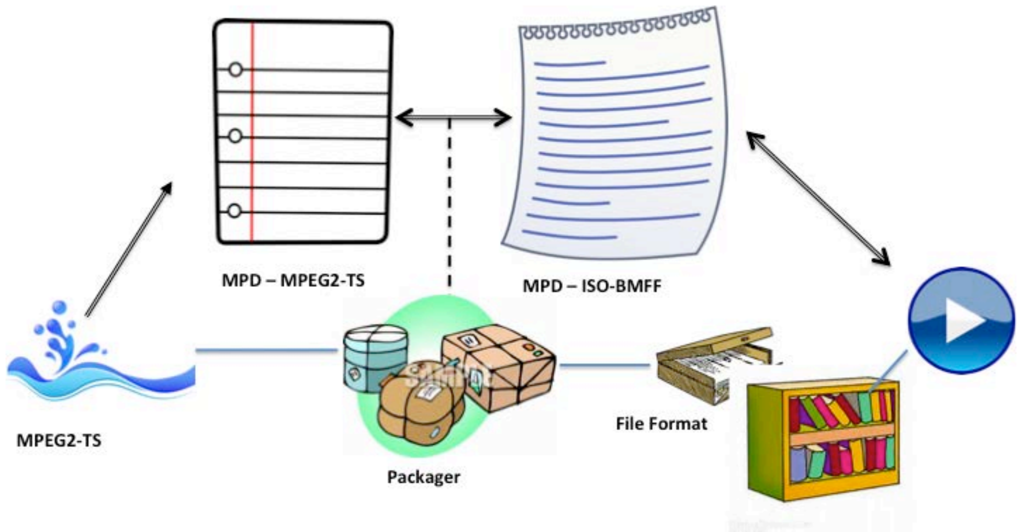

Figure 5 - MPD conversion between MPEG2-TS and ISO-BMFF

This is a new area in application guidelines development, but with the convergence of platforms, one would expect this part of the application guidelines to grow in importance -- especially with the migration to IP based platforms. Plausible applicability of this type of development could happen around same stream codec switching, network to server agent and browser presentation, hybrid broadcasting (broadcasting content with some areas fetch by an IP connection), rendering HDR content, or conversions between HDR and SDR.

3. Conclusions and Recommendations

This paper describes how application guidelines are essential in adopting a standard or set of standards into a service. They can reduce ambiguity, complexity, and corner cases, while improving interoperability. This is accomplished through constraints on standards, so as to create a viable service, populated with affordable products. With the convergence of several delivery platforms, applications guidelines will also increase in importance in order to create consistent service experiences. This involves unifying service features and the signaling between components in the system. Lastly, with the application of conversion constraints, this paper indicates that application guidelines need to consider the E2E media content chain, even while specifying details in only one area of this chain. This paper cites several examples from today's next generation technology efforts, and some historical ones as well, to illustrate how application guidelines increase the adoption of a standard into multiple application arenas.

4. Abbreviations

AFD	Active Format Descriptor
ARIB	Association of Radio Industries and Businesses (Japan)
ATSC	Advanced Television Systems Committee
AU	Access Unit
AUD	Access Unit Delimiter
AVC	Advanced Video Coding
BDA	Blu-Ray Disc Association

cDVR	Cloud Digital Video Recorder
CEA	Consumer Electronics Association
DASH	Dynamic Adaptive Streaming over HTTP
DASH-IF,	DASH Industry Forum
DPB	Decoder Picture Buffer
DPX	Digital Picture Exchange
DVB	Digital Video Broadcasting
E2E	End to End
EBP	Encoder Boundary Point
HDMI	High Definition Multimedia Interface
HDR	High Dynamic Range
HDTV	High Definition Television
HEVC	High Efficiency Video Coding
HRD	Hypothetical Reference Decoder
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IETF	Internet Engineering Task Force
IPTV	Internet Protocol Television
ISO-BMFF	ISO Based Media File Format
ITU-R	International Telecommunication Union-Radio Communication Sector
ITU-T	International Telecommunication Union- Telecommunication Standardization Sector
MPD	Media Presentation Description
MPEG	Motion Picture Experts Group
MPEG2-TS	MPEG2 Transport Stream
NAL	Network Adaption Layer
NTSC	National Television System Committee
OTT	Over The Top
PAL	Phase Alternation Line
PAT	Program Association Table
PCR	Program Clock Reference
PID	Packet Identifier
PMT	Program Map Table
RAP	Random Access Picture
SCTE	Society of Cable Telecommunications Engineers
SDR	Standard Dynamic Range
SDTV	Standard Definition Television
SECAM	Sequentiel Couleur Avec Memoire
SEI	Supplemental Enhancement Layer
SHRAP	SCTE HEVC Random Access Picture
SMPTE	Society of Motion Picture and Television Engineers
SPTS	Single Program Transport Stream
STSA	Stepwise Temporal Sub-Layer Access
TSA	Temporal Sub-Layer Access
UHDTV	Ultra High Definition Television

UHDTV1	Ultra High Definition Television Phase 1
VCL	Video Coding Layer
VFX	Visual Special Effects
VoD	Video on Demand
VUI	Video Usability Information
W3C	World Wide Web Consortium
WG	Working Group

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SCTE Society of Cable Telecommunications Engineers

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