Deploying IP Video Services, Architectures and Technologies from the Head End to the Home network.

Video Full IP - Architecture

A Technical Paper prepared for SCTE•ISBE by

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Introduction

In recent years we have seen the growth of IP-based content distribution services, not only in terms of services over controlled networks where we can highlight the IPTV deployments made by TELCOs companies, but also the proliferation of content distribution in unmanaged networks, also known as OTT (Over the Top).

But the new paradigm of TV consumption does not impact only in the distribution, but also and more important, in a better user experience(UX), with advanced User Interface (UI), new integrated applications and functions, new ways to consume the video, not only linear and on-demand but also different flavors of network-based time shifted video (like cloud reverse EPG (REPG), cloud Digital Video Recording (cDVR), Pause live TV, and others), new ways to show the information to the end user, where the video itself is not the only main piece, also the metadata that exposes to the end user enriched information and assists them with improved visual approach, searching and recommendations, or generating extra information, during special events, that allows end client interaction with applications related to the content.

In addition to this, there are also a new set of devices like PC, Tablets, Smartphones, Smart TVs, Consoles Games, etc., these are in general known as Consumer Electronic (CE) devices. They are starting to be used more and more to consume video services, and even more, there is an interaction between those CE devices and the traditional STB that are using in general in the cable operations.

The cable industry must be prepared to move in this direction, and the purpose of this paper is to explain how our company is transitioning to video over IP delivery. We have already moved from legacy Digital TV (DTV) to Hybrid (DTV+IP) system and now, finally, we are starting to deploy Full IP Video delivery. The explanation will include the drivers that generate these necessities of the migration towards IP world, as well as the technologies and architectures involved, starting in the headend using High Efficiency Video Coding (HEVC) compression technologies allowing not only High Definition (HD) definition but also Ultra High Definition (UHD), the System Delivery Platform based on cloud which controls advanced functionalities like HTML based user interfaces, network DVR, reverse EPG and others, the media transport -not only over DOCSIS access network but also over FTTH[1]-; and in the end the challenges and opportunities to deliver video in the home network using WiFi connectivity for customer electronic devices and for IP Set Top Boxes.

This document will describe which are the new necessities in terms of TV services' user experience, the definitions and first steps to move from Legacy TV system to a new ecosystem that allows satisfying those necessities. Then it will enumerate and explain some drivers to evolve the ecosystem towards a Full IP system. It also will take a look at which are the possible IPs mechanism to distribute the different types of video services, and finally, it will go through every domain, from the Head End to the Home Network explaining which are the changes that the operator will introduce finally to move to Full IP video.

[1] The document will mention FTTH in some cases, but the focus is specially HFC networks, however, most of the concepts are similar.

Content

1. Definition of Managed and Unmanaged Services and Convergent Video System.

Before starting with the explanation of the different systems over which TV services can be provided and then the explanation of why we are moving to an IP video ecosystem, we will make a distinction between what we will call managed and unmanaged networks as well as managed and unmanaged devices.

Managed networks are those ones in which the transmission of information/data can be guaranteed by managing the quality of service over it. For example, fixed telephony network is a managed network, as it is the IP network with quality of service policies over which telephony services are provided, on the other side, the Internet is an unmanaged network.

Managed devices are those ones which are controlled by the operator. The operator is who specifies the hardware (HW), software (SW) and applications that must be installed and executed over those devices, the end user just use them for the specific services that the devices were designed, and the user cannot install other applications that are not in the operator catalog or store. STBs are examples of this managed devices.

On the other hand, unmanaged devices are those ones that the end client can control, they can install a different kind of applications or even more they can modify and install the Operating System of those devices. For example, Personal Computers (PC), Tablets, Smartphones are examples of unmanaged devices.

In the video world, we could also add an extra level a separation between managed and unmanaged content, where the managed content is the one that the operator can ingest in the video system, it can configure the different video parameters, it also manages metadata and right of the content based on different technical and commercial agreement. Contrarily the unmanaged content is the one that operator cannot control, for instance, content that can come from OTT providers or content that could come in general from 3rd parties CDNs (Content Delivery Networks).

In Figure 1 it can appreciate the different combinations of uses cases that could be possible, where the complete managed services it shows the combination at the top of the picture (framed in red), this is the case of the Legacy DTV system or even more the Legacy IPTV system.

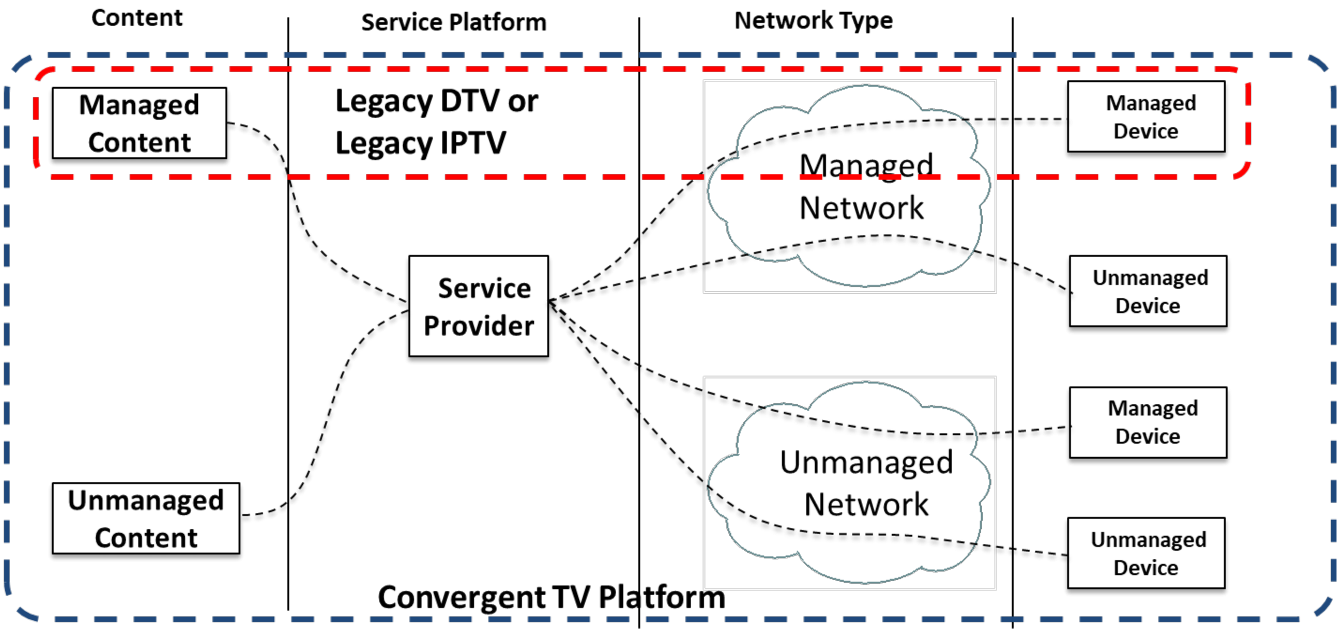


Figure 1 – Managed and Unmanaged services.

2. Driver to move towards Full IP Video Systems – a Convergent TV Platform

As it could be appreciated in the Figure 1, the traditional DTV or IPTV systems are very limited in term of type of devices where the services can be consumed, networks where the home network or more generally the devices can be connected, and the content sources (or applications) the end client can consume or use on their devices. On the other side, the legacy DTV system has strong limitations in terms of UX. We can split the problem into different planes, the first plane is related to the media distribution and devices where the media[2] is consumed, and the second plane is related to the user experience and control plane.

Regarding the media distribution the DTV networks generate huge limitation, that is where the customer can consume the content, consuming video on this system require a managed device that is an STB, which has to be connected to the COAX in the home. Today the operators provide services not only over HFC networks but also are deploying their services over xPON networks, Mobile or wireless Networks, xDSL and why not directly over the Internet, when the user moves temporally to other areas where the Operator that user belongs it does not have a managed network. All those networks have a common factor “IP” as a common mechanism to connect the services.

On the other hand, the end user does not consume video services only with STBs, but also in mobiles and stationary unmanaged devices (smartphones, tablets, PC/MACs, console games, smart TVs) which are mostly connected in home networks using WiFi, stationary devices that are most of the time connected at home, but mobile devices could be connected outside the home, in other 3er Party WiFi networks or 4G networks.

[2] With the term of media in general we are meaning video, audios, subtitles, etc.

As you can see, leaving side DTV system, all the networks aforementioned are IP based network. The Figure 2 and Figure 3 represent the different networks where the services must be provided including also the Home Network.

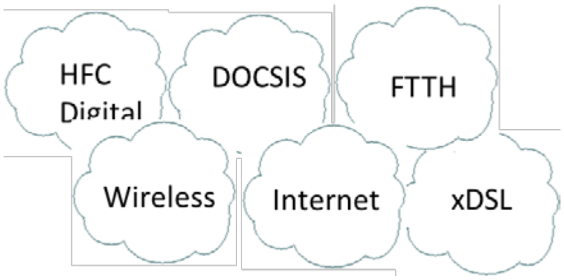


Figure 2 – Different kind of network to provide the video services

Figure 3 – Home Network (1)

On the other hand, we must consider the control plane that allows managing the service and user UX. In traditional DTV system, the control is limited to add or remove some video services packages Live TV, premium channels, Subscription VOD (SVOD), to buy video content based on Pay Per View (PPV) or Transactional VOD (TVOD). At the same time the presentation of the information to end user is limited and most to the functionalities are based on local applications on the STB that could or not exchange very basic information with DTV video Platforms, in addition to this is very complicated to modify or develop new services or applications, for instance the applications can base on Multimedia Home Platform (MHP), Open Cable Application Platform(OCAP), JavaTV or even more proprietary solution, that most of the time requires very specific programming skills to do changes or new functionalities, and the development time is in terms of years.

Nevertheless, OTT providers use much simpler and well know technologies that allow developing and improving their services in an agile way. They are “web technologies”, and in this world the UX is based on very well know technologies like HTML, JavaScript, Document Object Model(DOM), CSS, Webservers and Web Application servers, open source Databases, etc. and it uses lightweight protocols such as HTTP, REST vs RESTFUL open API, etc. The control plane is a distributed system that run-in end client devices and in the cloud, most of the logic is resolved not at the end user devices but in the cloud. In that way, a new functionality or change can be introduced very quickly. Figure 4 shows the architecture Model View Controller that decouple the application in three layers: 1) "Model" that represent the data-related logic that the application and finally the user work with, the "Presentation" or "View" that is the component that generates the logic of the UI, how the end client will see the information in the screen and how they interact with the application, and 3) the "Controller" that links the Views with the Models, the business logic occurs at the Controller, for instance in case of video applications it could manage which catalog has to be presented to a specific user with specific set of video packages and/or entitlements. Or for instance, the metadata (that could be stored in the data Models) is needed not only to have control over the media but also to provide information about it to the user. We could create extra Models to enrich with different sources of information, take information from the user behavior and generate recommendations, and to combine with other not traditional metadata sources to present a richer and improve EGP and/or Catalogs.

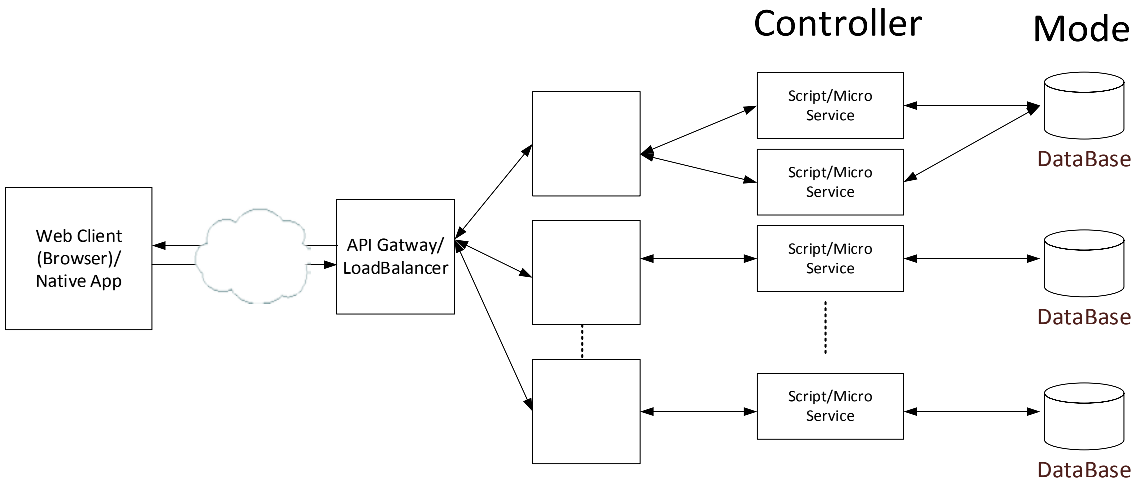


Figure 4 - MVC Model

This kind of architecture gives us some benefits over traditional DTV architecture and technologies.

- Much better and user-friendly EPG
- Elastic demand
- Open interfaces to change, improve or develop new functionalities.
- Easy to integrate with other platforms that allow integrating new ways to consume video (CuTV, REPG, etc.)
- Easy to integrate others 3rd party applications (for instance with another OTT video service that complement offer that Communication Service Provider (CSP) has)
- Personalization not only of the UI but also to the complete service at all
- Introduce companion devices functionalities.
- Its applicable not only to traditional CE devices but also to managed devices like STBs

An extra issue that we have in our DTV implementations, is that the system that we have deployed (more than 10 years before) is based on Motorola Digicipher II (DCII) scrambler, because of different legal and commercial constraints in the LATAM region, the only STB vendor can provide devices for this DTV system is the owner of the DCII technology, that generate a “lock-in” with the STB vendor leading to expensive STB’s constraints[3].

Finally, the evolution of technologies helps the migration towards IP. The new encoding technologies like HEVC video generates a better performance in network usage and the make easy to have the extra network capacity to deploy new lineups (that requires simulcast with the today's DTV lineup). The requirements of 4K and UHD content require new STBs to support that kind of content, so to protect future investment it is better to use technologies that have a long-term support, and then to use IP STBs instead DTV STBs. New STBs are based on more open OS like Linux and/or Android TV, which allow working with the web models that were described above.

[3] SmartCards cannot be sold in the region, if they could the costs are not good enough for the business

Figure 5 – Technologies evolution helps the migrations towards IP

All the drivers that were mentioned previously show a clear path to move the TV services directly over IP. For that in HFC networks, we must use DOCSIS, but that is not free, we need available bandwidth in the spectrum to allocate more DOCSIS capacity, now not only for High-Speed Internet services, and other data services, but also to transport the TV services. That could be the very first issue to deploy a FULL IP Video Service, but as it mentioned the system can be splited into two layers, data plane and video plane, and actually most of the features that generate an impact in the UX, new functionalities, etc. are not relative with the media itself but with the signaling and control layer of the service, the media that is the heaviest in terms of network resources could be kept until the resource (spectrum in terms of MHz) is available, over the today networks (DTV). So here is where the Hybrid system appears, where the control plane is based completely over IP and the video could be based on IP (generally Content on Demand[4] and some low audience linear channels) and the linear TV is based on DTV. This concept is depicted in the Figure 6, where the control plane (in red) is represented by the HTTP/HTTPs protocol to communicate the devices with IP Video Service Platforms and HTML4/5 for UI, meanwhile, the video could be transported over IP Network or over traditional QAM like it was done in HFC network.

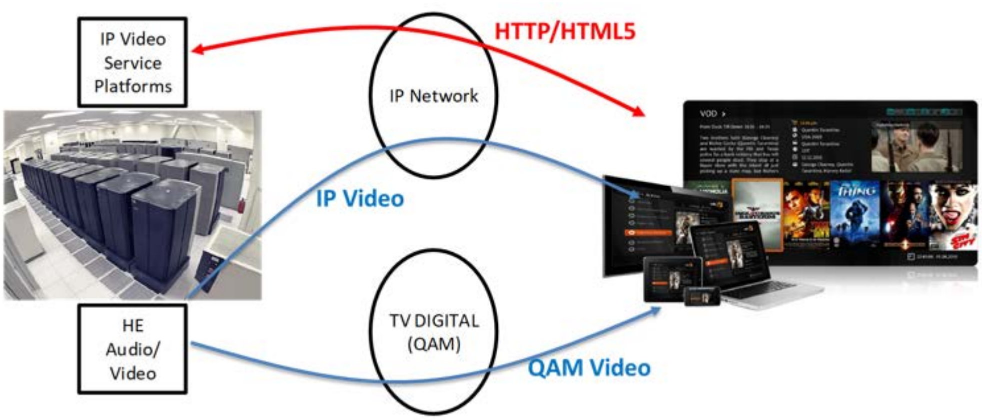


Figure 6 – The Hybrid scheme.

3. Where are we and which is the goal?

Telecom (former Cablevision Argentina) started to roll out a project, that was called "@TV" during 2015 to deliver the best in class entertainment services to its subscribers, to increase market penetration and to gain competitive advantage. @TV takes advantage of the latest technology solutions including the IP Video Service Delivery Platforms based on web technologies, Conditional Access (CA) and Digital Rights Management (DRM) system that allow control and protect content; Origin Server and Content

[4] aka VOD or Video on Demand

Delivery Network (CDN) to prepare the media and their distribution on any kind of device to provide the next generation IPTV multiscreen video experience based on cloud.
@TV offers the following services: Linear/Live TV, diverse types of VOD models, Time-Shifted TV (TSTV), Network DVR (nDVR), Restart, Reverse EPE (REPG), advance UX, recommendations, companion device functions, bookmarks between devices, profiles in the same account, etc.
The first phase of this deployment was based on unmanaged devices (Android, iOS, PC, MAC, and Chromecast) and on managed devices Hybrid STB (DCII Hybrid STB).

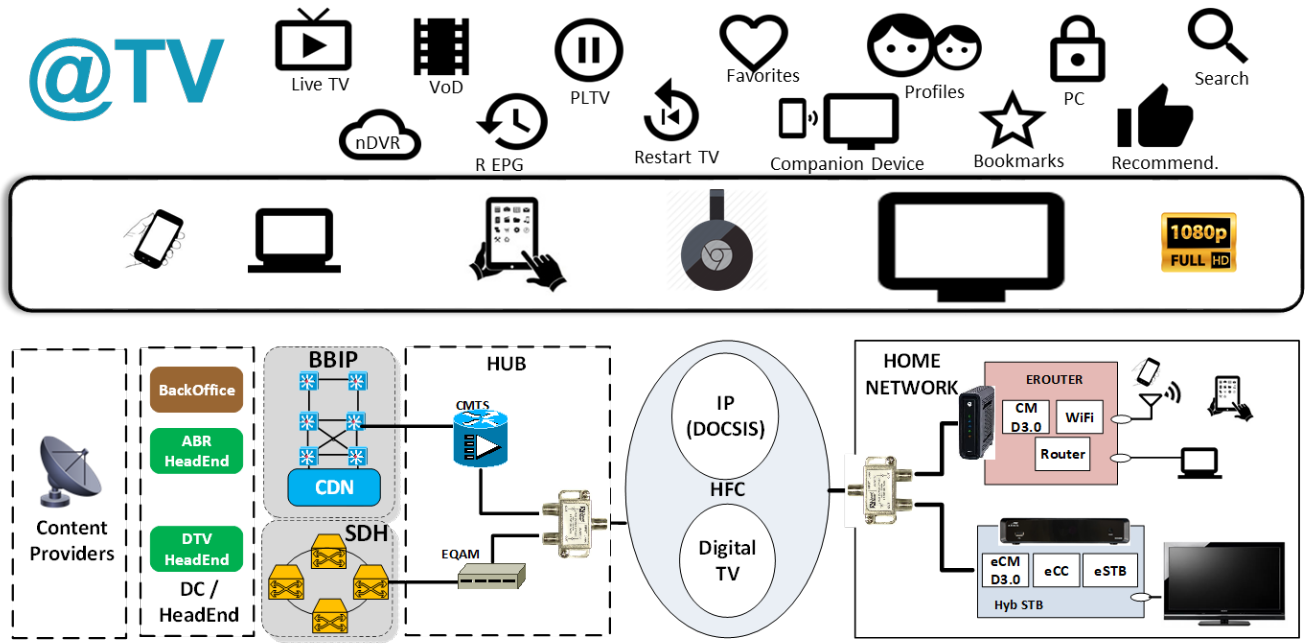


Figure 7- Hybrid ecosystem solution

To do this there is an ecosystem that is described in Figure 7, which is divided into platforms and networks, from the content reception, until it is consumed by customers in their homes and devices.

- The HE systems that receive the contents and process them to accommodate the formats to the needs of the different types of devices connected to different access networks
- The Backoffice Systems that oversee managing the video services that the user receives, protecting the contents, etc.
- The transport network that carries the contents from the HE to the access. The CDN is what allows the distribution of video using streaming technologies, like ABR, in a scalable way, it will have more explanation about that in the next sections.
- The different types of access networks to which the homes and/or devices of the clients are connected.
- And finally, the home that is challenging ecosystem where administration is not completely controlled, for example, the location of the devices and customer-provided equipment (CPE) in the home impact the quality of the service.

At this stage the System provides two different mechanisms to stream video:

1- DTV which is based on TV MPEG2-TS protected with Motorola Digiipher II (that is shown in the Figure 8 below as Legacy CA), as today this is a legacy mechanism that is used to stream Linear Content for Digital TV services; on the Home Network side Hybrid STB will receive these services.

The encryption is done in the Edge QAM equipment, so the video signal that is transported in MPEG2-TS is modulated, and it is sent to the access network HFC, then Hybrid STB demodulate the signal and decrypt the signal when it is authorized to (the STB has an embedded CableCard -DCII). The Hybrid STB is also connected in a secure way with the STB Controller (Legacy CA DCII) in the Head-End (HE) through legacy Out of Band (OOB) or DOCSIS STB GATEWAY (DSG) technology. The video distribution from the HE to the Edge Quadrature Amplitude Modulation (E-QAM) is based on L2 IP network transported over Synchronous Digital Hierarchy (SDH).

2- IP Streaming based on ABR transport and protected with DRM. That mechanism will be used to stream linear services and On Demand services. These streams are received from the content providers (Live and on Demand) and then ingested into the Origin Server. The Origin server receives the Live Content in several profiles using Adaptive Transport Stream (ATS) after transcoding process and it also receives on Demand Content in several profiles of MPEG4 Part12/14 after transcoding or directly from providers. The videos are stored in a NAS in a common format and delivered using Just in Time (JITP) method, that is when a given user get a piece of content the playout server of Origin Server packages and encrypts the content in real time. DRM assists JITP with asset encryption and delivers DRM license to client devices via a secured path. That is depicted as IP Unicast ABR in the Figure 8.

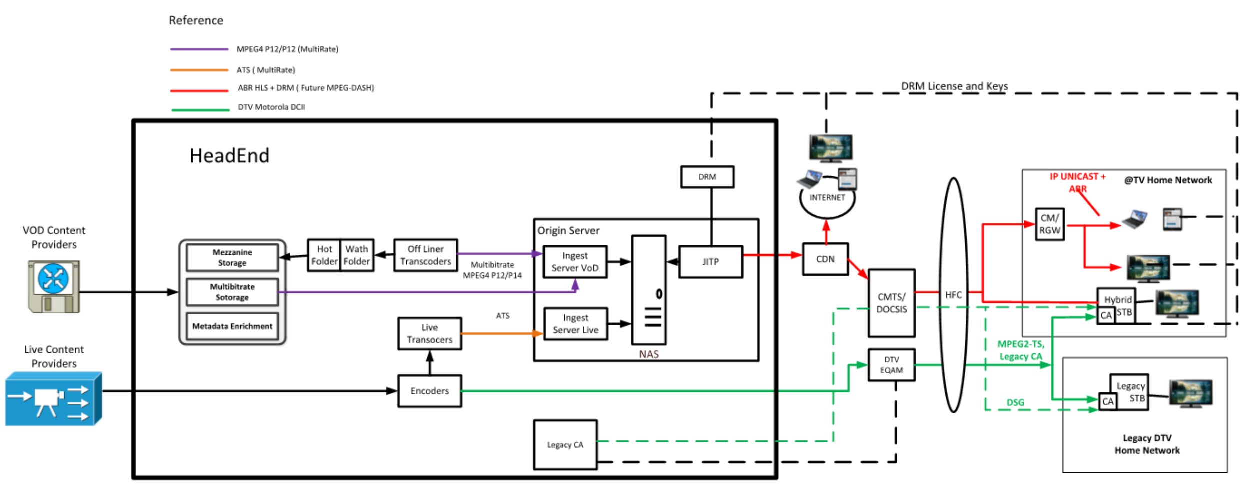


Figure 8- DTV and ABR Streams

To deploy a quick solution, the DTV encoders were reused as a source of Live TV Transcoders which generate the ATS for the Origin Server. As it will be described later in this document, it is not possible to generate the source for a Full Video IP transmission from the DTV HE and a new HE is required for that.

It is important to point out, such as it can be noted in Figure 7, that the home network is connected to two different access networks DTV and DOCSIS. The STB has an internal embedded CM (eCM) that provide the IP connectivity to the STB, this eCM does not provide connectivity to other devices inside of Home Network, it is needed a second CM that is in an EROUTER (showed as CM/RGW in Figure *8*) which provide internet connectivity to other devices in the same home.

The goal is to add the BO functions, HE element, transport and access mechanism and Home network capabilities that allow distributing video directly over IP, using an IP STB connected in the home network as “any other[5]” device, replacing the QAM by IP, so in the Figure 6 the ecosystem could avoid the QAM network. In the Figure 9 now appears the Full IP TV system combined with the previous one. There are some new components that are shown in the picture, for instance, a new Head End, an IP STB that is connected to the home network, there are also IP STB connected not only to HFC networks but also to FTTH networks or directly over Internet as a Managed devices over unmanaged networks, the idea is to reach those steps in a gradual way, with the same ecosystem, protecting the existent investment.

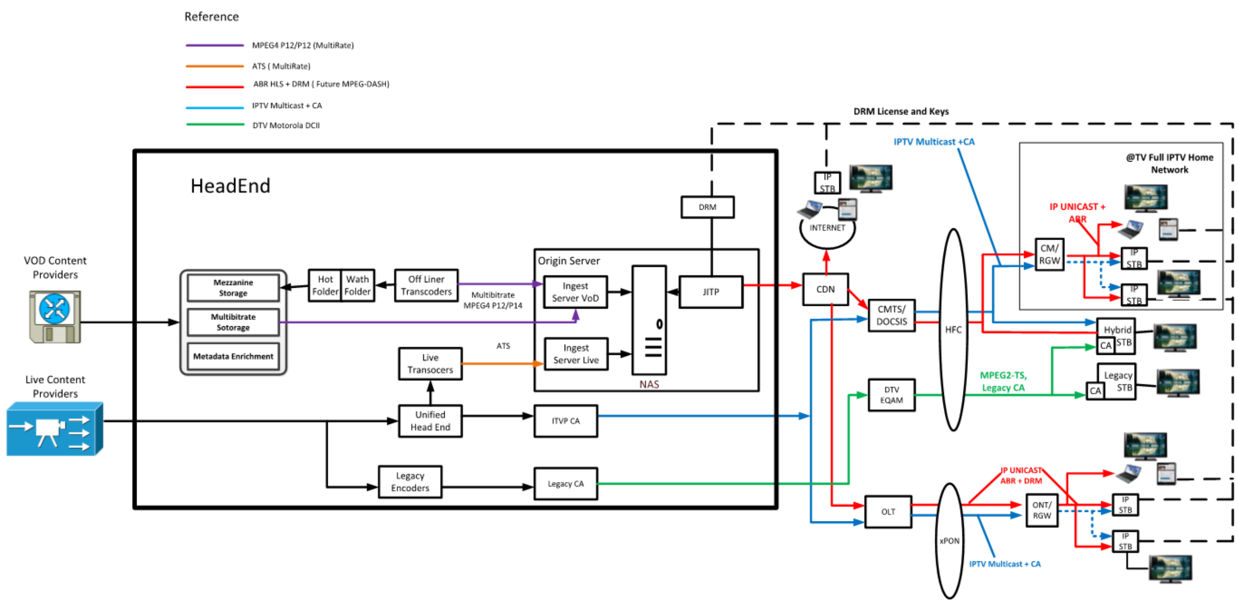


Figure 9 – Introduce the Video Full IP service

The document will explain what are the changes that we should introduce to meet with this goal, but first in next two sections we should understand a few more details about the video transmission mechanism and the audience behavior and which are the implications to replace the QAM network by all IP (DOCSIS in case of HFC).

4. Video Distribution and Audience Behavior.

4.1. DTV , Video over Internet and Hybrid distribution.

From the transport and access point of view, we can identify two kinds of services that the system must distribute over the network: Linear content and Content on demand (CoD), in the second one we could include VOD, CuTV, REPG.

The linear service is a kind of video traffic that is constantly requested by the end users, all of them are consuming the same content simultaneously with high concurrency of the users in many parts of the network. Linear TV services could be Live content (sports, news, etc.) but also movies, programs, etc. that are transmitted in a scheduled way. On the other hand, the second one (CoD) is requested by user request, and the concurrency is considerable lower than linear.

[5] We should remember that if we have to consider a Managed Service as was explained in Section -1 , the connectivity of those IP STB must be managed in any way, the document will cover that point in the next sections.

This type of service is translated in practical terms into a greater or lesser consumption of resources of the transport and access network, the main one being the consumption of bandwidth in the access network where the resources are in general limited.

In the DTV system the linear content is based mostly in Broadcast distribution[6] and the CoD is Unicast, both are digital video that is generated in the HE, distributed over IP network and modulated on the access network using Edge Quadrature Amplitude Modulation (EQAM), which receive video re-packetizes into MPEG transport stream and digitally modulates the transport streams onto RF carrier. Conceptually this distribution scheme is depicted in the Figure 10.

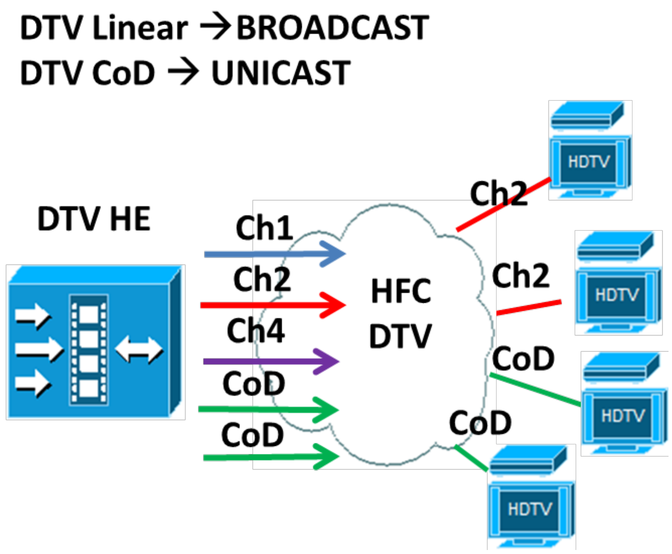


Figure 10 – DTV Video services distribution.

In the case Liner TV for the Broadcast mechanism, the network is sizing by the number of channels. All of the linear content is available in the network even when no user is consuming it. For instance, this case is shown in Figure 10, channel 1 and 4 is in the network but there are not clients that are tuning this channel. Let's note that that means that are networks resources that are being wasted but they are not really used by STBs. So, in DTV for Linear services the HE sends the channels to network, and all the channels are in network even when nobody consume those signals, when a given STB wants to consume a specific channel, it should look for in the network, for instance, the frequency where the channel is modulated, the program inside the transport stream, etc.

For CoD the content is pushed to the network only based on user request, and the even when two or more clients are watching the same content, there is a copy of the content for each one, let's remember that in CoD every client could to start, pause, rewind, do fast forward the content, so even when the "movie" could be the same, it could be shifted in the time and then that requires different copies for different users, that is because Unicast is used.

In contrast to DTV systems, that are managed networks, the Internet is a completely unmanaged network, and so the mechanism to distribute video is completely different. Fist at all those mechanisms must be based in very standard IP protocols, they use TCP/IP as transport and HTTP or HTTPS to encapsulate the

[6] There exists another more efficient mechanism in DTV that is Switched Digital Video (SDV), but that is not the case in our company and it is not explained in this document.

video, that allows transport it easily over internet, even more, it could work on devices connected behind Network Address Translation (NAT) or Port Address Translation (PAT) that are widely used in IPv4 Home Networks. Besides this layer 3 IP networks do not allow to propagate broadcast between layer 2 domains, so for both kind of services, Liner and CoD Unicast is used. The Figure 11 illustrate that case, when a device has to consume a linear channel, that device ask for this content to network (in fact the devices get the content from a Content Delivery Network (CDN) that it is described later) and then the content is routing over the network until it reach de device, if other device tune the same channel then the same happens and therefore there are two copies of the same content on the network, as you can see the sizing of the network for linear services grows up proportionally to the devices that are consuming those services. Same happens for CoD.

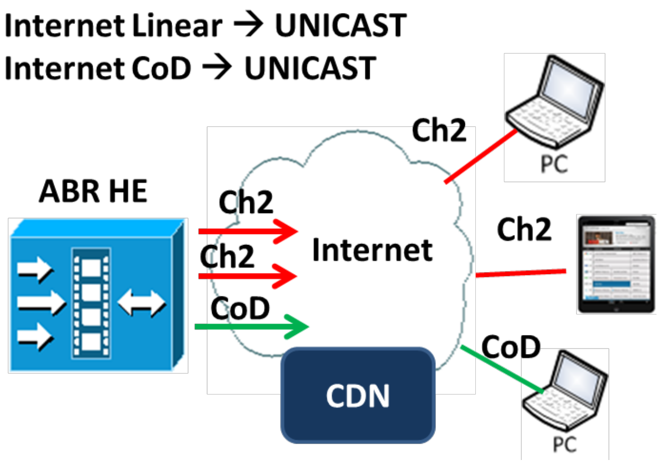


Figure 11 – Internet Video Services

There are different video streaming techniques, like HTTP download, Adaptive Bit Rate (ABR) that also uses HTTP/HTTPS as transport, Peer to Peer Video, etc., but the most widely used is the ABR, which allow to play out the content almost in real time, the quality of the video is adapted to the network quality, CPU devices capacity and other factors that could depend on the player implementations and flavor of ABR mechanism (2).

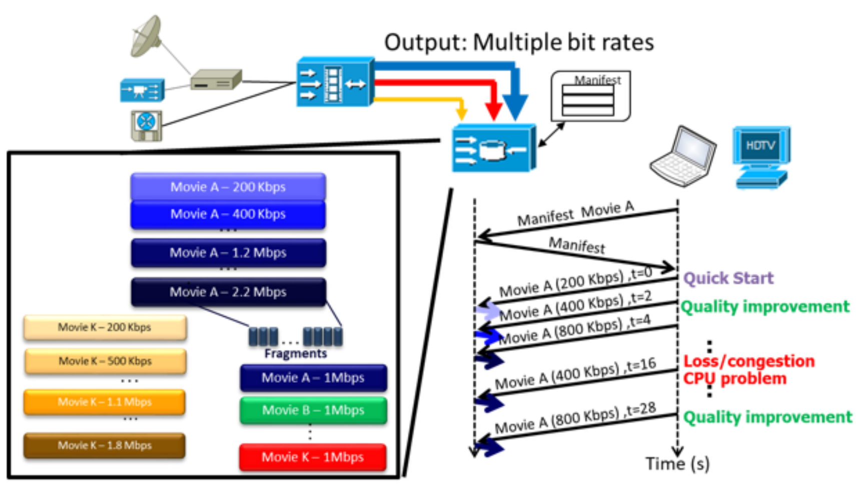


Figure 12 – ABR Streaming

Figure 12 shows conceptually how the ABR streaming works, first at all it must be generated different copies of the same content, different resolutions and bit rates, that are called profiles, then every copy is segmented into small chunks, each segment only has just some video's seconds, and then a special file that is called playlist or manifest is generated, this file contains the URL of every piece of segment of every profile, so when the end device has to consume a video, it starts getting this manifest, and read the URL of the first chunk (generally the lower bit rate profile to have a quick start) and according to the player strategy in function of the network quality, CPU's device capacity or others it could start to get better and better profiles and improve the video quality.

Let's understand now how the IP ABR streaming is originated and distributed in more detail.

4.2. Head End - Video Origin Server and CDN.

In the Figure 8 a block called Origin Server (OS) is the HE component that is in charge of to generate the different profiles of Linear and CoD video, and to make them available to be consumed by the clients through the CDN. Figure 13 is a zoom over this component.

Video OS works as an HTTP Origination Server (Web Server with Video Enhancements), its goal is: to ingest, store in NAS and deliver VoD content using HTTP ABR format, a mechanism to receive, buffer and deliver Live content (that comes from broadcasters) using HTTP ABR format, and to provide a way to reach end-user devices that support that kind of format and delivery mechanisms. Video OS is made up of several components to get more performance and efficiency.

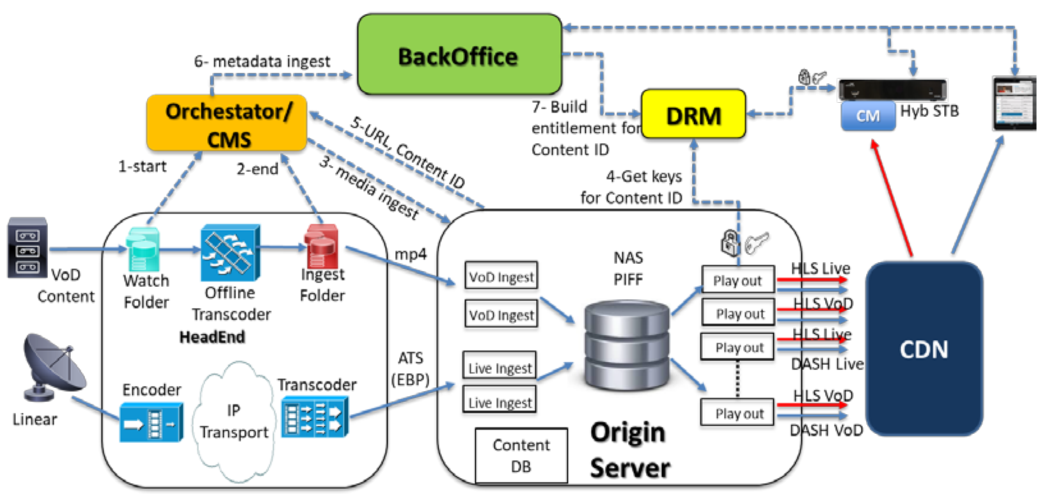


Figure 13 – Video Origin Server

VoD Ingest Server ingests video that could be in MP4 (format created by the Moving Picture Experts Group (MPEG)) as a multimedia container, or IIS Smooth Streaming Media Video (ISMV), or other formats, and stores it into NAS in Protected Interoperable File Format (PIFF) format (pivot format), for doing so, it receives an order from Orchestrator to queue a job that fetches content from Watch/Ingest Folders using FTP or HTTP, once the ingest process ends up the URL which points to VoD content is passed back to the Orchestrator/Content Management System (CMS).

Live Ingest Server receives video from On-line transcoders which deliver them using some kind of Adaptive Transport Stream over IP Multicast (3) (CableLabs ATS-EBP is preferred, but it could be others), this video is kept into a live buffer (time-base programmable size) that is useful to create and continuous update live manifest/playlist files with a programmable window length and to create DVR assets (those that are used for nDVR, CuTV, REPG, nPLTV, and TSTV in general services) , for doing so, it receives in advance an order from the video BackOffice (BO) through Planner Content DB to queue a job that makes permanent those segments/chunks when they are within the live buffer and are going to be part of the DVR asset. URLs for live content points out to chunks/segments in a live buffer and are populated in the BackOffice when creating channels, URLs for DVR assets are passed back to BO Planner Content DB. Those URLs are requested by the devices when they want to play out a given content.

Playout Servers receive requests for playlists and contents from CDN or from end user devices directly (it doesn't matter if is a VoD, Live or TSTV service), create playlist/manifest on the fly, take content from live buffer or NAS, encrypt and package it on the fly and deliver to CDN or end-user device. For doing so, Video Origin Server communicates with Digital Right Manager (DRM) using a protected path to create an encryption key for that content at ingestion/buffering time, and it receives that key (and the rotated keys) through using same protected path at delivery time for encrypting, packaging video and adding URL that points to key server (generally inside the DRM) into playlist/manifest, so content that leaves Video Origin Server is DRM protected. Playout Servers are also capable to deliver diverse types of ABR formats, Figure 13 shows HTTP Live Streaming (HLS) (4) and MPEG-DASH (5).

As it was described previously ABR is a unicast scheme video distribution and sizing of the system (OS and network distribution) is based on the number of devices, therefore using OS as the system that deliver the stream directly to the devices could generate a big issue for scalability, for instance in terms of I/O capacity of the NAS to be read by the Playout servers. But that is not the only problem, the video must be distributed from the HE to the end client using an IP transport Network and using Unicast. That has two major issues:

1) The distance and therefore delay that could exist between the end user device and the HE, as ABR use HTTP/HTTPs as transport and those use TCP the delay could generate a limitation for the bit rate that the connection could reach.
2) Again, the sizing of the transport network to support every Unicast stream between clients and HE systems.

CDN fixes these two major issues (and others), instead of that end devices get the content directly from OS, they get the content through cache layers. Figure 14 shows conceptually how the CDN works, the end device instead to get the content directly from OS, it gets from Edge Cache, if the Edge cache has the content (what is considered as a hit) that is being requested then it delivers directly, if the content it is not in the Edge cache, that means a cache miss, and then the Edge looks for it in the Intermediate Cache (IC), that is another layer of the CDN, where it can be again a hit or miss, with a hit it is served by the IC to the Edge and finally to end device, or if it is a miss the IC asks for the content finally to the OS.

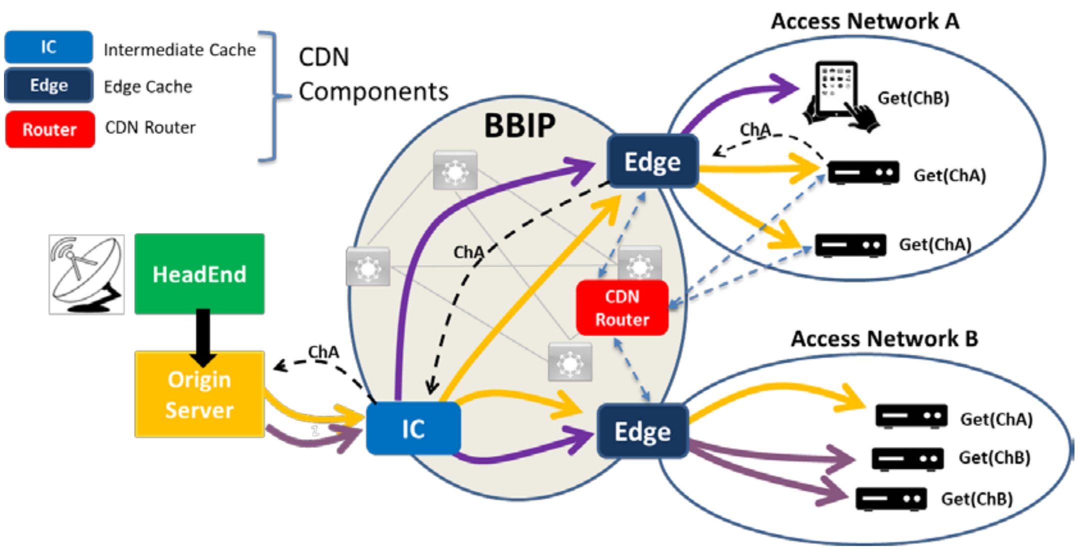


Figure 14 - CDN

Each time that a content is serviced by a Cache node, it stores the content by a given expiration time so next time that other devices get for the same content it can respond directly. For linear content where the content is consumed in real time, when a device asks for a given channel the next device that asks for the same one there is a high probability of a hit and the traffic over the IP Backbone (BBIP) is proportional to the Edge cache nodes deployed and not to the number of end-user devices. With the same logic, the traffic that is requested to the OS is just proportional to the number of IC nodes. At the same time if the Edge Node is deployed at the border of the access network, as it is depicted in the Figure 14, then the delay between these nodes and the end client devices could be minimized, which mitigate the problem of the delay in TCP.

There are diverse types of CDN topologies, with more o fewer numbers of intermediate layers, but at the end, it must have an Edge cluster, that is a set of Edge cache node that works all together caching content and serving a same set of customers. This cluster should be placed as close as possible to the end user devices, for instance at HUB or in a regional site that connects several HUBs, the topology will depend on the distances and amount of traffic that the Edge cluster must deliver to the access network. The way, in which the end devices determine which is the Edge cluster, and particularly the Edge Node inside the cluster, is based in a CDNs control layer, that works as routing layer for the CDN, and this routing layer must have logic that must be a function of devices' IP source, geolocation, load of the Edges nodes, it could also be aware of the cache content to redirect the device to the edge that already has the content and increase the hit probability, it may use the user-agent of the device player, and others that in general depends on the CDN implementations.

4.3. Linear TV and Content on demand based on Hybrid distribution.

If ABR is used in a managed network, and the Communication Service Provider (CSP) could guarantee the quality of the network, the same technique that is used on Internet to distribute the video can also be used to distribute the video in those controlled networks and even when the ABR has the capacity to adapt the quality of the video to the network conditions, if the quality of the network allows the ABR uses the best profile then the quality of the video could be guaranteed. On the other hand, if the STB could support this ABR mechanism then it can be used the same technique for Managed or Unmanaged networks and for Managed or Unmanaged devices. Even more, the same DRM can be used for each of those combinations. The **Figure *22***Figure 15 shows the case where there is a Hybrid STB that can receive Linear TV from DTV HE, but also have an embedded CM that allows receiving IP ABR streaming for both Linear TV or CoD.

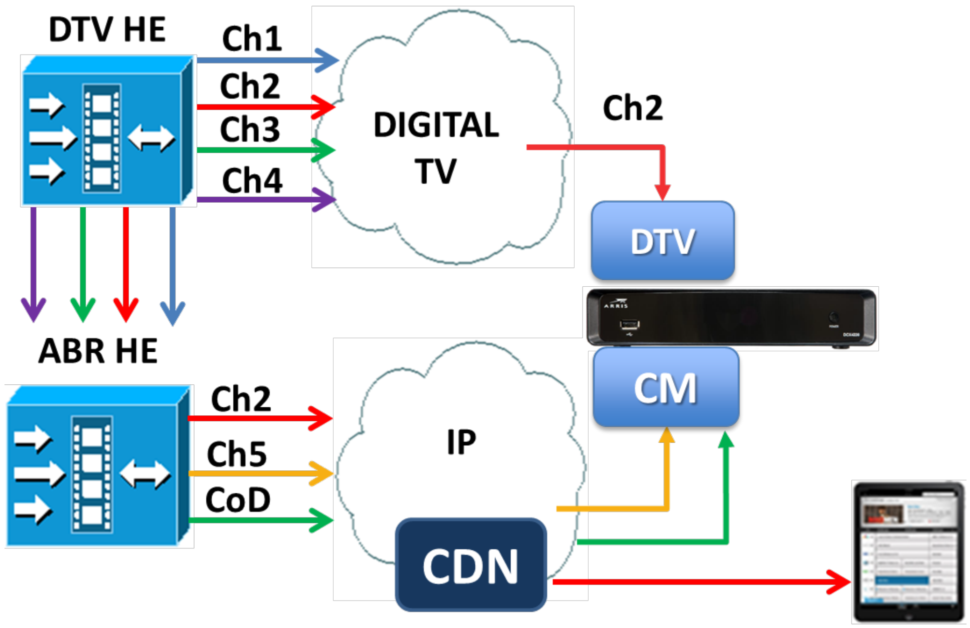


Figure 15 – Hybrid video distribution, DTV, and IP ABR

As a resume Table 1 shows which are the available distribution mechanism for video in a hybrid ecosystem such as presented up to here.

Table 1 - Resume of video distribution mechanism for Linear and Cod

	TV Digital	**IP**
Live TV	Broadcast (BW -> Nro Ch)	Unicast (BW -> Nro Clients)
CoD	Unicast (BW -> Nro Clients)	Unicast (BW -> Nro Clients)

The interrogation that it could be asked is, what's happens if in the in the Figure 15, instead of using the DTV the system configure the STB to receive all the channels over IP, based on the ABR mechanism that it has been explained above? In that scenario the complete ecosystem it could be considered based on a FULL IPTV video, all the BO interfaces are in IP and the video distribution too. However, that could have some issues. One of them is the delay in the video that ABR introduce, as it was explained the ABR mechanism is based in chunks/segments of some video's seconds which are buffered, the player needs to receive some of those segments previously to start the play out, and that generate delay against the real signal (between 20 and 40 sec) that it is not acceptable for live content like sport events. However, there are some new Low Latency ABR technologies that are considering this issue and probably could be addressed in the future (6). Alternatively, as it was aforementioned the CDN helps with the scalability of a Unicast distribution on the BBIP, from the Headend until the access (edge) but how does the access should be sized to support the video unicast distribution?

So, to answer this question we are going to analyze the audience behavior.

4.4. Impact of the Unicast in the Access Network - Audience Behavior.

Fixed access networks can be divided into two kinds: 1) point to point access network like xDSL mostly using in TELCO companies, where there are dedicated resources from the access to node until end client and 2) share access networks, like DOCSIS or FTTH, where the resources are shared by all the clients that are connected to those access network. In the first case, point to point access network if it is considered that CDN it collocated at the side of the access node, the video unicast traffic for each client, at access level, will impact in the client itself because each client has a dedicated link. Contrary to this, in share access network the video distribution based on Unicast for a given client will impact in all other clients that share the same access network. So, the question that shows up is if the Video Unicast distribution mechanism is scalable in such kind of networks. And the answer is that it will depend on the number of devices that consuming video using Unicast and the capacity of the access network, and the number of devices consuming a given type of content depends on the audience behavior, so to analyze that it will use a real case that it was taken from a day where there was a very important sport event and the traffic in the CDN reach its maximum value until that day.

The picture showed in Figure 16 is the traffic of the CDN, dark green and light green is the traffic of two different clusters that are used for unmanaged devices[7] and Hybrid STB, meanwhile, the orange traffic is the cluster dedicated to unmanaged devices that are Chromecast. It is important to differentiate this traffic from the rest of other unmanaged devices because the Chromecast is connected to a big screen, like an STB, and the user behavior is different.

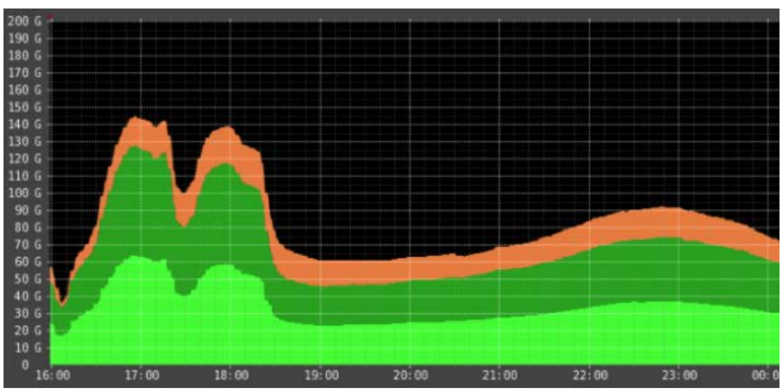
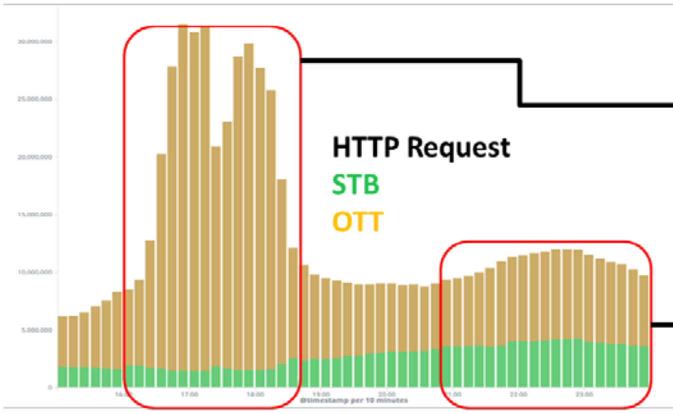


Figure 16 – Video CDN Traffic March 23th – 2018

The picture shows two peaks between 16:00 and 19:00 hrs., that is the time slot where the event was broadcasted, every peak corresponds to the first and the second half of the match soccer match. Another highlight of the graphics is that those peaks overpass the peak in the TV prime time that is from 21 to 24hs. (at least in Argentina).

[7] PCs, MACs, Android and iOS devices.



Device Type	%Request a CDN	Bit Rate [Average Mbps]
STB	10%	4,17
OTT	90%	2,44

15% Chromecast @3,14Mbps

Device Type	%Request a CDN	Bit Rate [Average Mbps]
STB	43%	4,36
OTT	57%	2,86

44% Chromecast @3,16Mbps

Figure 17 – CDN HTTP Request by Device Type.

If we analyze which devices were those that consume this Unicast traffic from the CDN it is observed that during this sports event 90% of the devices were unmanaged (OTT) and just 10% were managed (STB), that can be appreciated in Figure 17. Let's remember that Hybrid STBs consume linear services from DTV system and not from the CDN, so most of the STB HTTP request is because CoD and not because linear TV consumption, contrary to that most of the OTT HTTP request were because of the live sports events. During the prime time the amount of HTTP request from OTT devices and STB are quite similar (43% for STB and 57% for OTT). It is important to point out that the sporting event was during working hours where the people are not in their home so they consume the video using their OTT devices.

Another highlight is that the average Bit Rate in the OTT device is lower than for STBs, that is because STBs are connected in a managed network where the throughput is assured, while the OTT most of the time are connected in wireless networks, which are unmanaged networks, such as home networks where WiFi is regularly a best effort shared network, 4G or even worst in 3G mobile networks.

In Table 2 there are the different set of video profiles for various HD and SD kind of movies or live programs, there exist a different kind of content complexity in terms of for instance movies with soft or abrupt changes of scene, sports events, news programs, etc. There is a wide variety of bit rates and resolution from the lower 400kbps up to the higher 7528kbps. Most of the time the content is in HD @1280x720 and sometimes @1920x1080, and the average that STB is in 4.36Mbps what means that they are using the highest of the profile that is mainly because there are QoS to support the distribution mainly in the access.

Another high spot to point out is the case of Chromecast devices. They are generally connected at home WiFi network, as you can see during the sport event just the 15% of OTT devices were Chromecast, while during the prime time almost half of the OTT devices were Chromecast, let's remember that Chromecast is a device that is connected to a big screen (in HDMI of TV set) and receive the stream from network through WiFi, and in general that provide better throughput than in 3G/4G networks and that is because the average bit rates in Chromecast devices are bit higher than in OTT devices in general.

Table 2- ABR Profiles

HD Low Complexity (HDLC)					
Bitrate (kbps)	H	V	FPS	Profile H264	
530	424	240	29.97	Main	2.1
1040	640	360	29.97	Main	3
1480	854	480	29.97	Main	3
2100	1024	576	29.97	Main	3.1
3000	1280	720	29.97	Main	3.1
5500	1920	1080	29.97	Main	4.1

HD Generic Complexity (HDGC)					
Bitrate (kbps)	H	V	FPS	Profile H264	
604	424	240	29.97	Main	2.1
1192	640	360	29.97	Main	3
1 726	854	480	29.97	Main	3
2420	1024	576	29.97	Main	3.1
3450	1280	720	29.97	Main	3.1
6514	1920	1080	29.97	Main	4.1

HD High Complexity (HDHC)					
Bitrate (kbps)	H	V	FPS	Profile H264	
678	424	240	29.97	Main	2.1
1344	640	360	29.97	Main	3
1972	854	480	29.97	Main	3
2740	1024	576	29.97	Main	3.1
3900	1280	720	29.97	Main	3.1
7528	1920	1080	29.97	Main	4.1

SD Low Complexity (SDLC)					
Bitrate (kbps)	H	V	FPS	Profile H264	
400	320	240	29.97	Main	2.1
650	426	320	29.97	Main	3
780	480	360	29.97	Main	3
1010	576	432	29.97	Main	3
1200	640	480	29.97	Main	3.1

SD Generic Complexity (SDGC)					
Bitrate (kbps)	H	V	FPS	Profile H264	
454	320	240	29.97	Main	2.1
730	426	320	29.97	Main	3
894	480	360	29.97	Main	3
1158	576	432	29.97	Main	3
1366	640	480	29.97	Main	3.1

SD High Complexity (SDHC)					
Bitrate (kbps)	H	V	FPS	Profile H264	
508	320	240	29.97	Main	2.1
810	426	320	29.97	Main	3
1008	480	360	29.97	Main	3
1306	576	432	29.97	Main	3
1532	640	480	29.97	Main	3.1

Following, it will analyze CDN and Access Network capacity required to support a Full IP video distribution, instead of DTV based on Broadcast, using IP Unicast ABR for Linear channels.

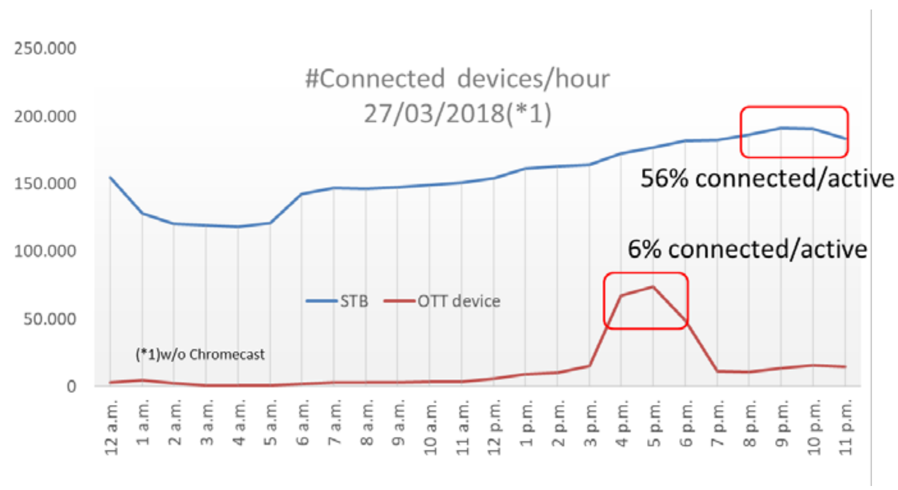


Figure 18 – Connected devices/hour

The Figure 18[8] shows the connected devices per hour during the day that it is analyzing. As it illustrates there is a peak of OTT devices during the sportings event, but this peak reaches just 6% of the total of active OTT devices in the system. That is the amount of OTT devices that mostly contribute to reach the

[8] 27/03/2018: 338,383 active STBs/ 1,169,663 active OTTs

140-150Gbps that it shows in Figure 17. At it can expect there are a lot of more OTT devices that STBs in the system, the average is 3.5 OTT devices per each STB, Nevertheless the behavior is clearly different, even when the STBs are less than OTT devices there are a lot of more STB devices connected and consuming video at the same time than OTT. At the prime time, there is a 56% of STB concurrency. Something important to point out is that this number of STB concurrency is in a regular day, but if the prime time it is overlapped with very popular sport event this STB concurrency could reach 80%, that can be appreciated in the Figure 19[9], that is the same graphic of connected devices/hour but during the "FIFA world cup". This event was on Saturday when most customers are in their home and it can be seen how the STB concurrency it is close to 80%, and even more, soccer is a very popular sport in Argentina and due to the others world cup's match during the day, the concurrency was almost flat the rest of that day.

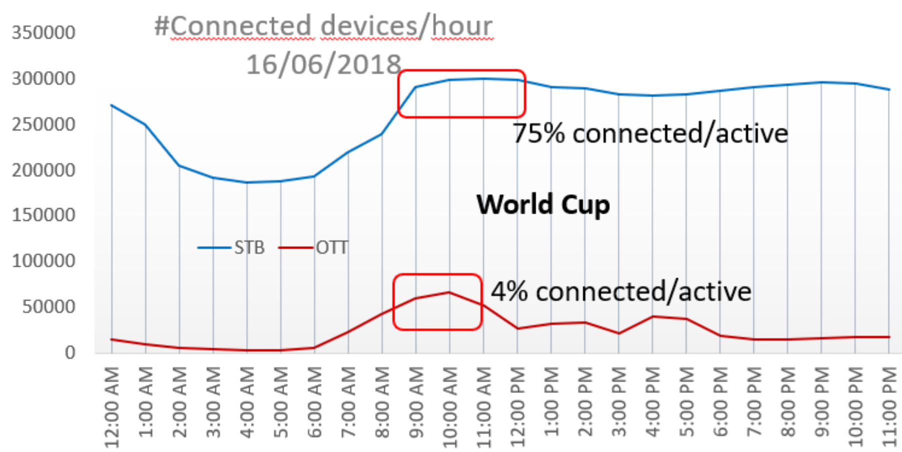


Figure 19- Connected devices/hour during the world cup

Therefore, we can use these figures to estimate which should be the DOCSIS Service Group (SG) capacity to support the Linear TV based on ABR Unicast, so let's assume:

- Average Bit Rate per STB = 4.36Mbps
- Max Bit Rate HD per STB = 7.5Mbps
- Max Bit Rate UHD per STB = 15Mbps
- HHPP/SG from 500HHPP/SG to 32HHPP/SG, Penetration 60%
- Two different cases of concurrency, for the average of 56% and for the case of very popular event 80%
- 1.5 STB per Home

[9] 16/06/2018: 403,407active STBs/ 1,570,135 active OTTs

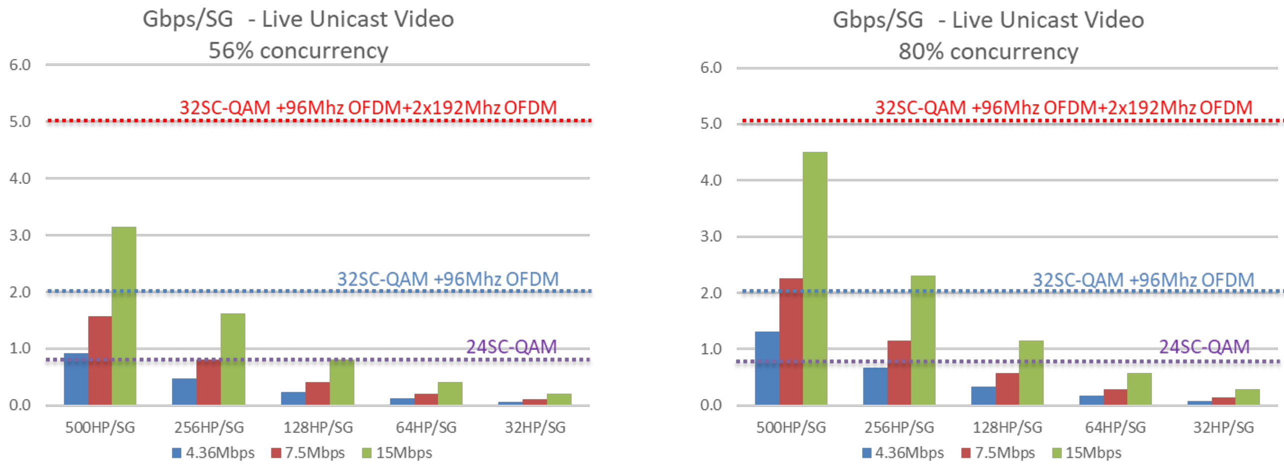


Figure 20 - Gbps per Service Group for Liner TV based on Unicast ABR.

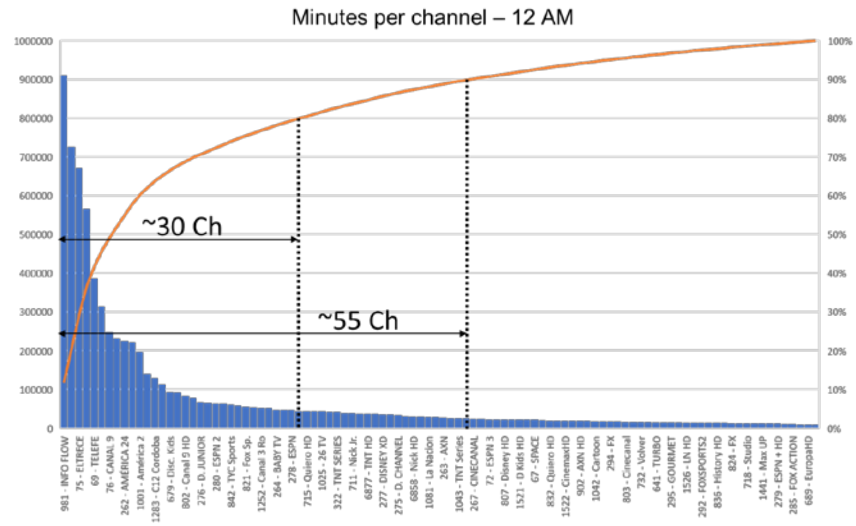
Figure 20 gives the capacity needed in the SG for different sizes of services areas (HHPP), for three video bit rates (today average, Max for HD and Max for UHD) and two scenarios of concurrency (56% and 80%), and the graphics give an idea of the boundaries of the SG capacity.

A real HFC plant with 24SC-QAM could provide almost 900Mbps, with 32SC-QAM channels and 1x96Mhz DS OFDM block it could reach almost 2Gbps and if it considers 2 more 196Mhz DS OFDM block it could get approximately 5/6Gpbps depending on the modulation profiles.

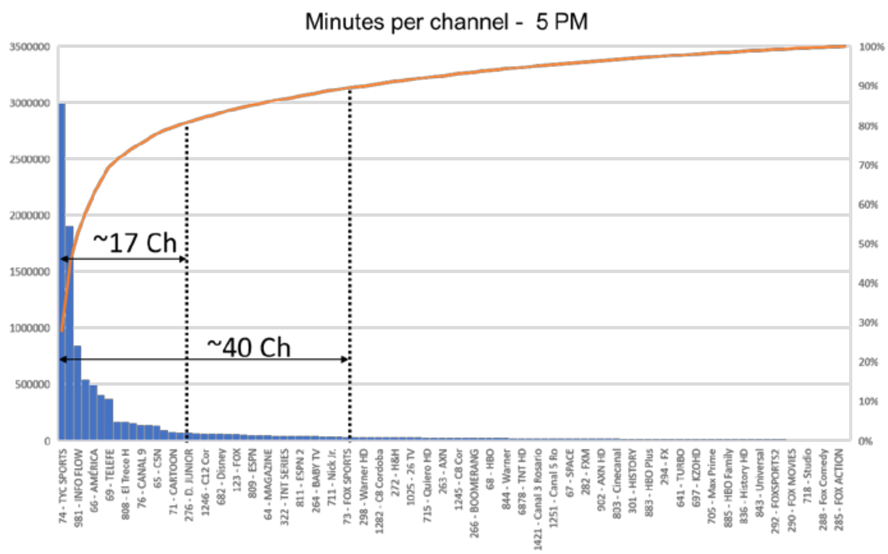
A conclusion here, in those scenarios and conditions the picture shows it is almost impossible to provide Linear TV using Unicast ABR just with 24SC-QAM, the network must support at least the first version of D3.1 and even with that, the SG size should be reduced at least until 128HHPP/SG, and that is only to support the linear TV services over DOCSIS, but the network must also support HSI services so possibly the SG must be reduced even more, 64 o 32 HHPP/SG. That is something that will happen during next years and very gradually, but today our network is not in those conditions, most of them are in 500 or 256HHPP/SG, and even when at plant point of view, it supports D3.1, the EROUTERs deployed are 24x8 D3.0. So, that way to provide Linear TV it could result very expensive and inviable in terms of investment. The example here was done based on DOCSIS, but similar analysis and results could be done in xPON, where for instance GPON or XG-PON networks that could achieve almost 2.5Gbps or 10Gbps in the downstream direction respectively.

The question that arises is: is the behavior the same for all the channels? As it can expect during a very popular live event the audience will tune the channel and at the same time, other channels will have less number of viewers. So, the other point that we should analyze is the audience behavior. If the channels are ordered from highest audience to the lowest audience, it gets a graphics like the one shown in the Figure 21[10], which shows the channels viewer distribution.

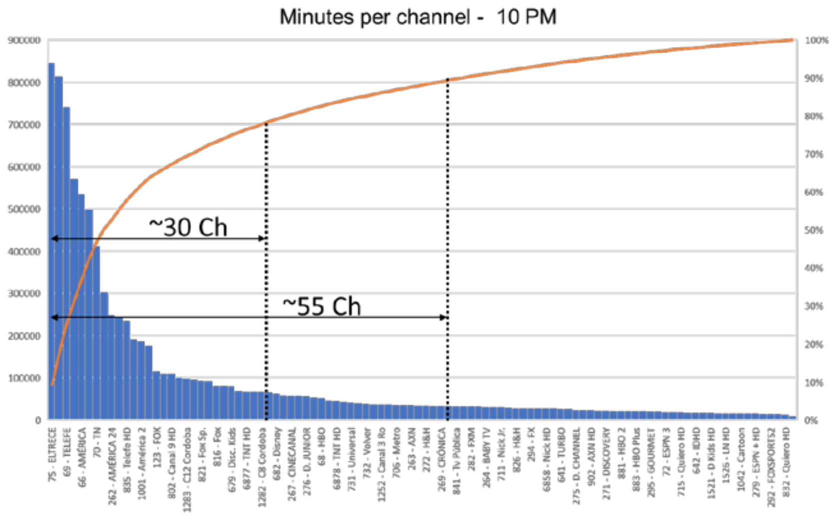
[10] The number of channels in the lineup is almost 200 channels the Figure do not show all of them at the tail of the graph.


Minutes per channel – 12 AM
~30 Ch
~55 Ch
981 - INFO FLOW
75 - ELTRECE
69 - TELEFE
76 - CANAL 9
262 - AMÉRICA 24
1001 - América 2
1283 - C12 Cordoba
679 - Disc. Kids
802 - Canal 9 HD
276 - D. JUNIOR
280 - ESPN 2
842 - TYC Sports
821 - Fox Sp.
1252 - Canal 3 Ro
264 - BABY TV
278 - ESPN
715 - Quiero HD
1025 - 26 TV
322 - TNT SERIES
711 - Nick Jr.
6877 - TNT HD
277 - DISNEY XD
275 - D. CHANNEL
6858 - Nick HD
1081 - La Nacion
263 - AXN
1043 - TNT Series
267 - CINECANAL
72 - ESPN 3
807 - Disney HD
1521 - D Kids HD
67 - SPACE
832 - Quiero HD
1522 - CinemaxHD
902 - AXN HD
1042 - Cartoon
294 - FX
803 - Cinecanal
732 - Volver
641 - TURBO
295 - GOURMET
1526 - LN HD
292 - FOXSPORTS2
836 - History HD
824 - FX
718 - Studio
1441 - Max UP
279 - ESPN + HD
285 - FOX ACTION
689 - EuropaHD

(a)


Minutes per channel - 5 PM
~17 Ch
~40 Ch
74 - TYC SPORTS
981 - INFO FLOW
66 - AMÉRICA
69 - TELEFE
808 - El Trece H
76 - CANAL 9
65 - CSN
71 - CARTOON
276 - D. JUNIOR
1246 - C12 Cor
682 - Disney
123 - FOX
809 - ESPN
64 - MAGAZINE
322 - TNT SERIES
811 - ESPN 2
264 - BABY TV
711 - Nick Jr.
73 - FOX SPORTS
298 - Warner HD
1282 - C8 Cordoba
272 - H&H
1025 - 26 TV
715 - Quiero HD
263 - AXN
1245 - C8 Cor
266 - BOOMERANG
68 - HBO
844 - Warner
6878 - TNT HD
1421 - Canal 3 Rosario
1251 - Canal 5 Ro
67 - SPACE
282 - FXM
902 - AXN HD
803 - Cinecanal
301 - HISTORY
883 - HBO Plus
294 - FX
641 - TURBO
697 - KZOHD
705 - Max Prime
885 - HBO Family
836 - History HD
843 - Universal
292 - FOXSPORTS2
290 - FOX MOVIES
718 - Studio
288 - Fox Comedy
285 - FOX ACTION

(b)



(c)

Figure 21 – Channels Viewers Distribution

This picture depicts which is such distribution during the event day (27/03/2018) at three different hours, (a) 12 AM previously to the event, (b) 5 PM during the event, and (c) 10 PM during prime time. Cases (a) and (b) shows that the 80% of the audience just watch 30 channels and but during the event the audience is concentrated in the channels that were broadcasting the event and then 80% of the audience is just in 17 channels. In general, the audience behavior can be fit to Zipf's distribution (7) (Figure 22), which has a form of power-law like following:

$$P_i = \frac{i^{-\propto}}{\sum_{i=0}^{N} i^{-\propto}}$$

Where the percentage usage varies as a power of channel rank, where N is the number of channels and α is a shape factor (8).

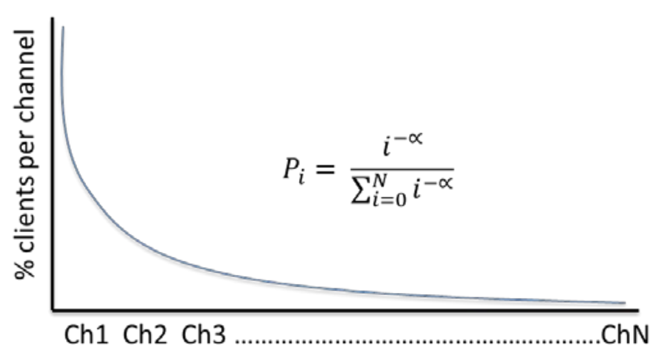


Figure 22 – Zipf Distribution

Share access network, like DOCSIS or xPON network, are divided into groups of services: N1, N2, N3, N4, etc. Conceptually, it could say that there will be channels that will have a high probability to be tuned in every network Ni, and others that are no so popular with low probability to be tuned and then only some clients in only some networks will be connected consuming those channels. It is represented in the Figure 23, where channel 1 is it a popular channel and 2, 3, 4 and 5 are no so popular, and it is possible to split those channels into at least two different sets, high concurrency events/programs, and low concurrency events/programs.

In the aforementioned explanations it was showed that Unicast Linear video distribution is not scalable for networks with more than 512/256 HHPP per SG, however one of the causes of that is the concurrency; if the audience behavior, for a given set of channels, is such as the concurrency is low, the unicast is an option that can be used. The Figure 21 a, b and c show that most of the channels have low probability to be tuned (low concurrency). So, there are a lot of channels that can be distributed by Unicast.

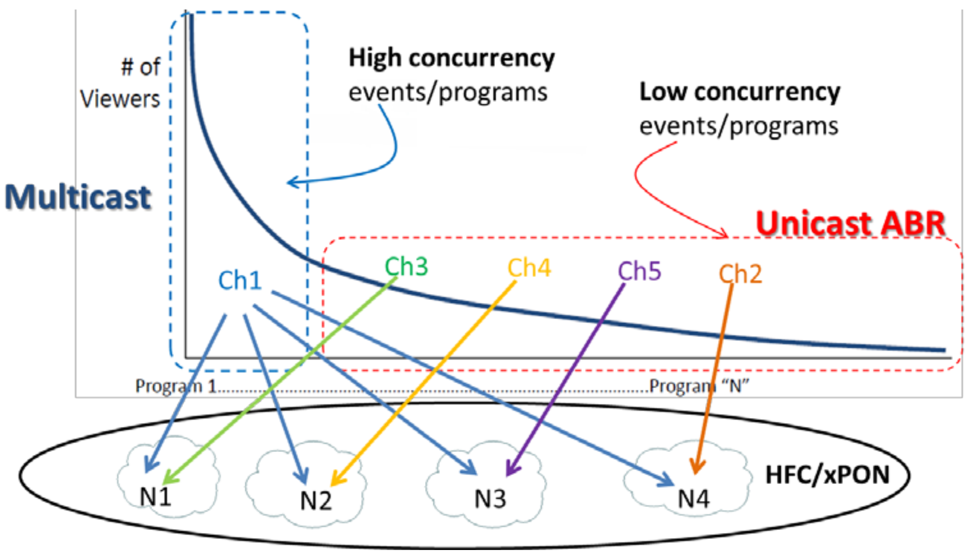


Figure 23 – High and Low concurrency events/programs

The problem that it should be addressed is the set of channels with the highest popularity because depending on the size of the SG it could have not enough capacity to support the linear services and the other data services (HSI, etc.). So, for those set of channels Multicast distribution is used. This mechanism allows replicating the same stream of information between several clients that are requiring it, with just one stream for all them. The concept of Multicast gain that is the relation of the amount of the clients that are watching the same channels. That generates a most efficient mechanism to distribute the linear video and then saves in the HFC/xPON networks resources. Then, let's supposed to have a lineup of five channels, in the Figure 24 there are 3 clients that are tunning the channel 1 and other that is tuning channel 2, the channel 1 it will appear on the network just then first client tune it, then when a second client wants to join to the same channel, which is called multicast group, then it just generates a JOIN message to this multicast group, and then multicast mechanism in the network forwards the traffic up to this second client, without necessity to generate a new video stream in the whole network.

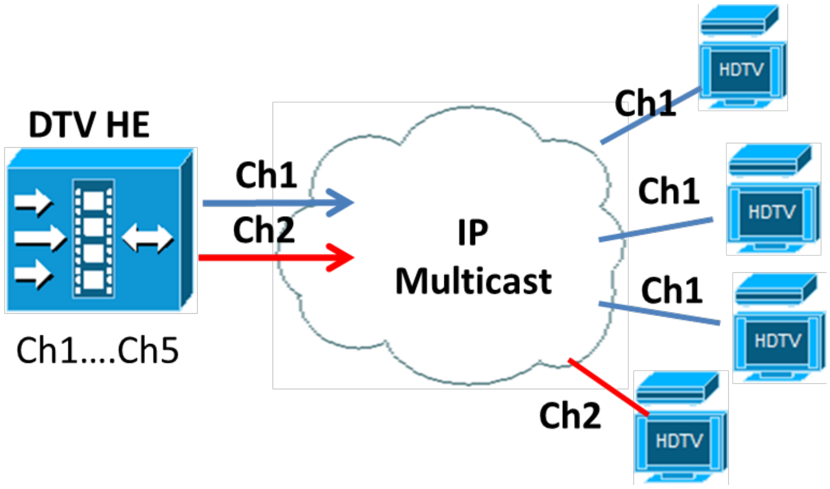


Figure 24 – IP Multicast Distribution

Table 3 gives a brief of was discussed during this chapter, about the different mechanism to distribute linear TV and CoD services.

Table 3 – Distribution mechanism to distribute TV services in managed and unmanaged devices.

	Digital TV	Unmanaged devices (OTT)	Managed devices (STB)	
			Not popular channels	Popular Channels
Live TV	Broadcast	Unicast	Unicast/Multicast	Multicast (Unicast only small SG)
CoD	Unicast	Unicast	Unicast	Unicast

As it was explained previously in broadcast transmission the sizing of the network depends on the number of channels and it is independent of the number of clients connected; contrarily, in unicast, it depends on the number clients connected consuming video but it is independent of the number of channels. In Multicast distribution, the network sizing will depend on the Multicast Gain, which is a function of the number of the client connected and the number of the channels.

When the number of viewers is low the Multicast Gain is low, which is also another justification for why to go to Unicast distribution in the SG with few numbers of clients. For the same the numbers of viewers bigger number of channels less saving in Multicast distribution, the Multicast Gain decreases, then if we kept the multicast for the most popular channels it could generate a big saving in term of resources.

5. Changes to reach Video Full IP system

In a FULL IPTV system, the Broadcast distribution that is used for Linear TV service must be replaced by an IP mechanism, and as it has been explained in aforementioned, for linear TV service there are two mechanisms that have to be used, Multicast for the most popular programs and Unicast for less popular programs. Then, the goal is to replace the QAM Video in Figure 6 by a complete IP distribution. This change will be traduced in modifications in every domain of the complete ecosystem from the

HE/Datacenter to the Home Network, going through IP transport network (CORE and BBIP) and the Access network. Figure 25 shows the Hybrid and Full IP video ecosystem and it highlights in red the modifications that must be introduced over the complete system. During the next section is going to explain deeper which are the changes.

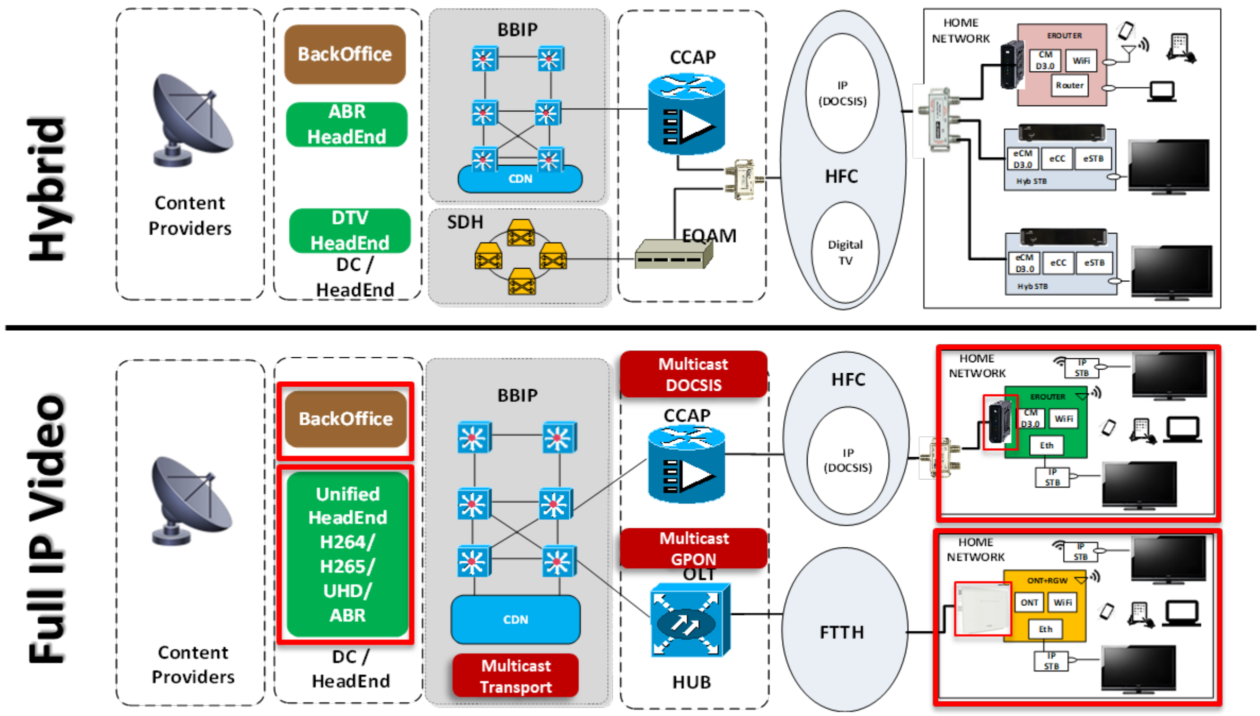


Figure 25 – Hybrid vs Full IP Video

Something important to point out is that the technologies are not the only change. There are several other changes at the process level in the company, for instance just to mention one of them the installation process in the home network, in the hybrid system there are not so many changes in this aspect, the technician kept installing the STB as a legacy DTV STBs, but now the IP STB is connected using new techniques, Ethernet, WiFi, PLC extenders, etc. And the new skills and tools are needed in the toolbox of the technician. In general, those changes are as difficult as the technology itself. Table 4 enumerates the main aspects to evolve from DTV to Hybrid, and then to Full IP.

Table 4 – Changes from DTV to Hybrid and form Hybrid to Full IP.

Domain	Legacy DTV	Hybrid System	Full IP Video
Head End	It manages the encoding system for Liner TV and VoD generating the MPTS for Linear and SPTS for DTV distribution.	Linear TV signals are reused, the current HE works with the Hybrid STBs. New ABR transcoding is needed to support CoD for any devices and Linear TV for unmanaged devices. It is transported over Unicast IP.	A new HE is required to encode the content in an appropriate format for the IPTV system. A new concept of Unified HE appears. New technologies like HEVC, Virtualization, UHD, are exploited.

Domain	Legacy DTV	Hybrid System	Full IP Video
	Conditional Access system where the different Linear TV packages are defined. Legacy VoD Back Office to manage the VoD distribution over QAM.	New IP Back Office is deployed to support the new User Experience, new CE devices, searching, the recommendation engine, etc. There is an integration with the Legacy DTV CAS to consolidate the Linear TV packages. A DRM is also needed to manage the rights in Unicast ABR distribution.	Some changes are required in other to signaling the Multicast Content and the DTV CAS is replaced by IPTV CAS.
IP Core and BackBone	Media is transported with IP over SDH or DWDM in L2 connectivity from HE to the Access networks.	It reuses the same transport mechanism used for Linear DTV. There are no configurations changes in IP Core or Backbone. A new CDN is deployed to distribute the Unicast ABR content. A new class of service must be configured in the network to prioritize Unicast IP ABR and the BO's signaling.	Linear TV requires IP transport on the IP Core and Network, Media is transmitted at Layer 3 (no more Layer 2 connectivity between HE and Access) Multicast routing protocol like PIM (or other) must be enabled in the IP Core and Backbone that connects the HE with the Access. A new class of service must be configured in the network to prioritize Liner IP Video over Multicast.
Access	Typically EQAM is used.	No changes for DTV. Specific DOCSIS Service Flows could be configured to assure the video ABR QoS.	Linear TV over MPTS signals modulated with EQAM is changed by Multicast IP SPTS transported over DOCSIS or GPON. Multicast must be enabled in DOCSIS or GPON.
Home Network	Linear TV or VoD are consumed in Legacy DTV STBs	A new Hybrid STB is required. Hyb. STB installation is the same that Legacy STB. New unmanaged devices can be used to consume the video services through the regular EROUTER that also provides HSI service. More than one CM in the HN, one for the EROUTER, another for every STBs.	A new IP STB is required. There are specific functions to enable or to develop in the ROUTER/ONT/RGW. Multicast must be managed in the HN. New installation scheme, ethernet, WiFi, WiFi extension. A new process of logistic, provisioning must be developed in the operator. The concept of COAX outlet connection disappears from the HN. HN management is a MUST (TR-069). There are no requirements to split the coax, the CM represents a unique Point of Entry and the HFC network termination.

Now it will go through the changes on HE, BBIP, and it will describe with bit more detail the Access Networks and Home network[11].

5.1. Video Head End

Starting at the Headend it is necessary to introduce encoders that could generate the video signals in appropriate formats, contrary to the DTV signals where the video uses statistical video multiplexing optimized for QAM to save resources, in IPTV system normally requires Constant Bit Rate (CBR) video. Another change that, could be introduced because the state of the art of the encoding technologies, is the possibility to use High-Efficiency Video Coding (HEVC or H265) which allow to save up to 50% of bit rate to encode video with same quality as H264. Taking advantage of the change a new concept in the head end architecture is also introduced, that is what it is called Unified Headend.

[11] BO also require some changes but that are not going to be described here, but briefly those changes are to support of video's URI with multicast address, and the IP Conditional Access (CA) integration.

Figure 26 depicts the HE Architecture today, where exists several encoding silos isolated. With this architecture every time that a new encoding technology is added the ecosystem adds a new HE system silo, so there are silos for MPEG-2, silos for H264, another for ABR transcoding, and then it will be necessary to add other for IPTV.

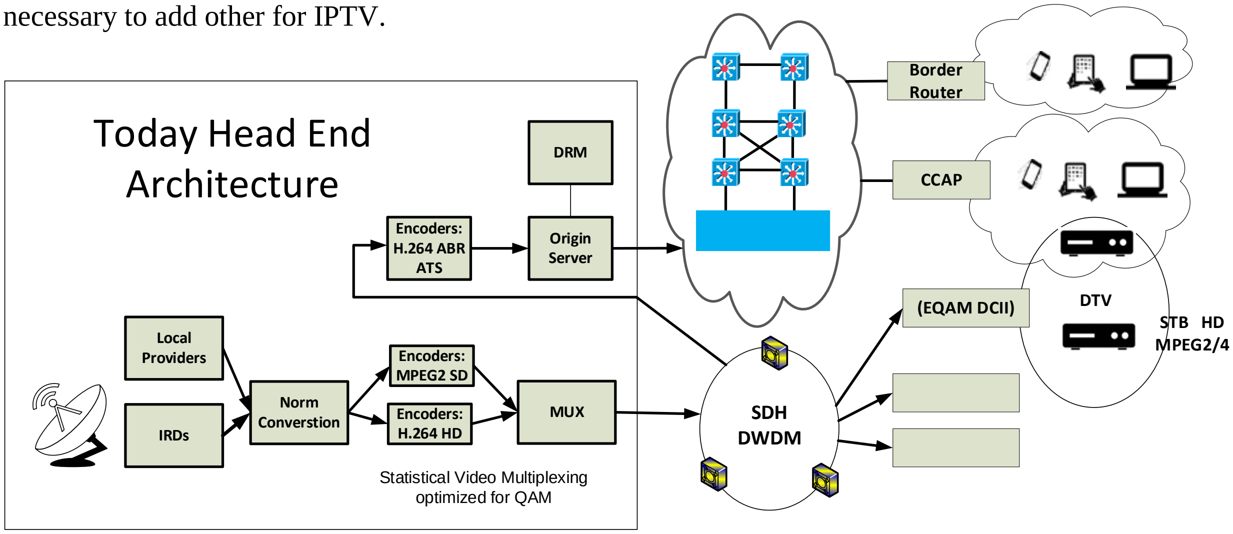


Figure 26 – Today HE Architecture

This scheme has some disadvantages, for instances:

- Every silo has its own infrastructure, a signal is carried from the source (Content Providers) up to every encoder, son there are Serial Digital Interface (SDI) cables between the origin of the signal and every encoder of every silo that must process the signal. When a new signal is added, then an operative task for cabling the new signal is required, the signal is connected to an expensive matrix and then from here cables for each silo. That is showed in the Figure 27 on the left.
- Each silo has their own roadmap of technology, and sometimes some features are available only in an HE system but not in all.
- The redundancy is local in each silo, so the same signal is redundant several times.
- In some cases, different silos are managed for different teams.

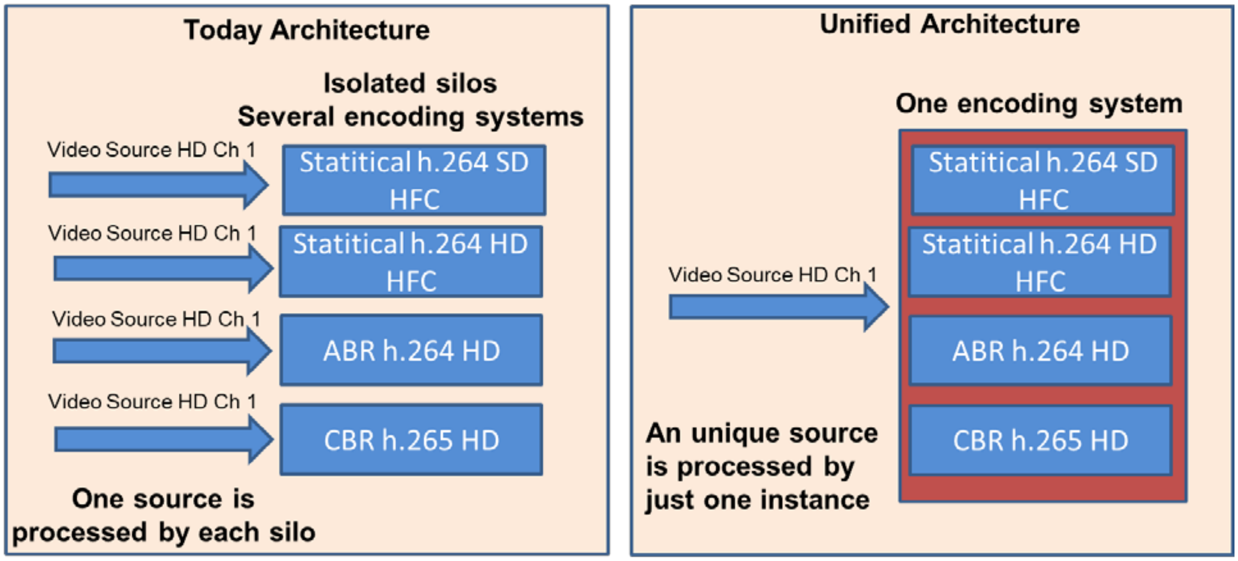


Figure 27- Several encoding systems vs Unified encoding system

The main idea of the Unified Headend is to have just one encoding system with several compression instances, then the system receives only one copy of the signal and it is proceeded by the correct instance. The different instances are virtualized and run over Commercial Off the Shelf (COTS) servers, the input could be IP or SDI, and depending on the server capabilities it is possible to run an instance in a server and that can deliver all the required formats. The advantages of this architecture are:

- This reduces the necessary infrastructure.
- Reduce the points of failures.
- The backup systems are shared.
- Improvement on the encoding algorithm could be deployed change the software version.
- Add a new signal means deploy a new virtualized instance, which is very flexible.
- Prepares the infrastructure towards a migration from the headend to the datacenter.

Figure 28 shows how the Unified Architecture is integrated into the ecosystem. The different outputs of the system are used to feed the different devices, on different networks. For example, one instance could deliver:

- The H.265 profile is used for IP STB connected in managed networks, the output of this instance goes through the scrambler (SCR) that together with the Conditional Access (CA) it is used to encrypt the video for IP STBs.
- The Multiple Bit Rate profiles in H264/H265 that generate the ATS feed for the OS, and the go through the CDN when a managed or unmanaged device get a channel in unicast distribution.
- MPEG2 or H264 Profiles used for DTV distribution like DVB, in cases of Analog reclamation (DVB EQAM) or for Analog modulators, in cases where it is necessary to provide analog TV.
-

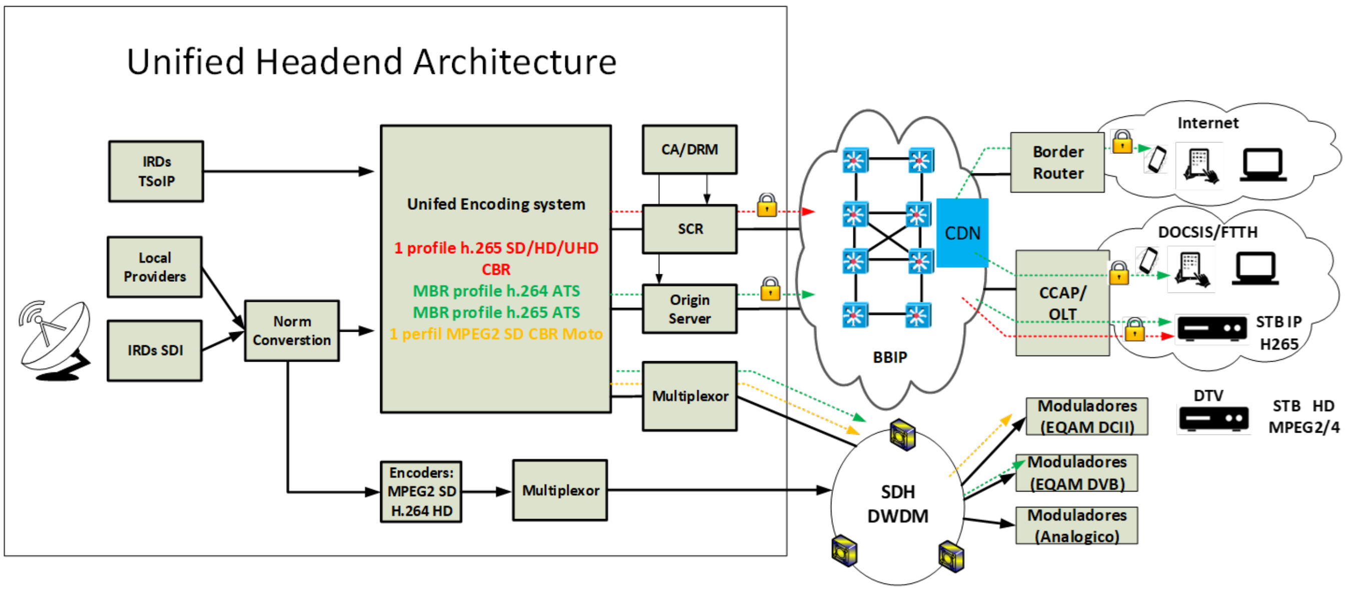


Figure 28 – Unified HE Architecture

5.2. Transport network

The signals that are generated from the HE must be transported to the access networks, for unicast distribution it was aforementioned how that is done in a scalable way using a CDN. But now we have to add a mechanism to forward the most popular Linear TV channels using Multicast.

Figure 29 shows how the Multicast mechanism works, it is based on a concept of groups of receivers (in this case the IP STBs) that are interested in receiving the same information, specifically here the video stream, the information is addressed with a Multicast IP, that comes from a special segment of IPs defined by the Internet Assigned Number Authority (IANA) in the range from 224.0.0.0 through 239.255.255.255 (9). These addresses are used as destination address in IP datagram, but a difference of other IP address there is not hosted on the network that has those address, these could be seen as “the address of the information” that the receiver wants to get, in our case it will represent a specific channel, and it will be represented as “Gi”. On the other hand, the information is originated from different sources, in these cases, they are the encoders or the scramblers, that are represented in an IP network by an IP Address “Sj”.

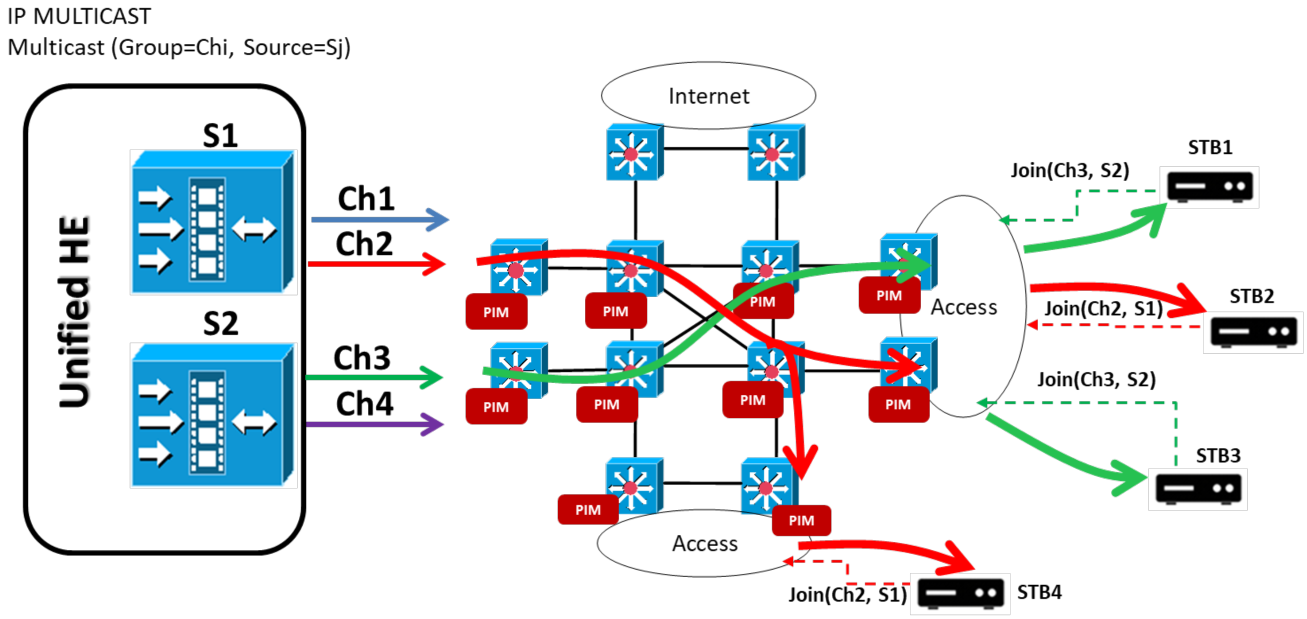


Figure 29 – Multicast in the transport network.

When an STB need to tune a channel, it must register to the multicast group Gi that carry this information. STBs use Internet Group Management Protocol (IGMP) which allows to a host ask for a membership to a local multicast router, this communication is done in a local network, at Layer 2. Local routers listen to IGMP information and sent out, with a given frequency, queries to host (in this case the STBs) that are connected in its local network, to discover which are the multicast groups that are active or not on that Layer 2 network. There are different versions of IGMP, but in this case, the IGMP version 3[12] (10) is used. Let's suppose that an STB1 tunes the Ch3, then it sends a Join IGMPv3 message where it informs to the local router that it wants to register in the multicast group G=Ch3[13] (which is an IP multicast address). When the local router receives this Join and realizes that it is not forwarding this multicast address, then it must request to the source the information.

In unicast routing, the forwarding's tables in the routers are based on the network's destinations, and those networks are manually configured or automatically learned with routing protocols. For multicast routing, the whole network must be configured to indicate to routers how to generate the forwarding tree between the source and the receivers. There are different options for that but here Protocol Independent Multicast (PIM) is used, and particularly when the source Sj of the information is known (that is the case of IGMPv3) PIM Source Specific Multicast (PIM-SSM). With PIM-SSM if local router receives a subscription to a given (Gi, Sj), then it forward that request to the PIM neighbors routers using the normal routing tables based on the Sj until that the request reaches the router that is connected to the source Sj, with this mechanism a route tree is built between the routers that were asked for the Gi and then the information is forwarded through the interfaces of those routers, finally reach the local router who forward the traffic to its local network and the STB1 receive the information. When a second STB (STB3 in Figure 29) tunes the same channel Ch3, it sends the Join to the local router but in this case, the

[12] Unlike of IGMPv1 or v2, IGMPv3 must define which is the IP address of the source where the information must be requested.
[13] The video is carried on SPTS and is transmitted using UDP, or RTP over UDP, then the client also informs the UDP port.

multicast has been already forwarded in the local network and the STB3 simply read the stream form the connected network.

When an STB change the channel, what happens is that firstly the STB sends a Leave message, which indicates to the local router that this specific receiver doesn't want to receive the information, and then the STB generates again a new Join with the new (Gi-new, Sj-new) for the new channel. When the last STB in the local network sends the leave for a given (Gi, Sj) the local router stops forwarding traffic of that multicast group toward the local networks. Eventually, that process continues in the rest of the network's routers and if there are no other receiver registered to this (Gi, Sj) the multicast groups it is not forwarded in the network until next Join.

5.3. Access Network

Once that multicast traffic reaches the access network the way in which every type of access network manages this traffic could be different. Multicast traffic in Layer 2 networks are mainly specified in Ethernet networks, but here the video must be distributed on DOCSIS or GPON14, which define a specific mechanism to forward the multicast traffic. Unlike DSL, DOCSIS uses a shared medium but provides tools to ensure Quality of Service (QoS) to each subscriber. In this section, it is going explain how DOCSIS support multicast traffic comparing the hybrid with Full IP video in terms of QoS and Service Flows (SF), and finally some issues that could arise with Multicast in DOCSIS.

5.3.1. Multicast in DOCSIS.

In DOCSIS® 3.0 (D3.0) MAC and upper layer specification (11) defines a flexible scheme for multicast to support Any Source Multicast (ASM) (9) and Source Specific Multicast (SSM) (10), as aforementioned the last one is what it used in this paper to distribute a broadcast linear TV services. Unlike previous DOCSIS® versions, where it works based on snooping IGMP messages (only IGMP v1 and v2) at CM level, in D3.0 the CM is not aware of the multicast, the responsibility of the Multicast control over DOCSIS, relies on the CMTS. That imposes the first constraint that is that the deployed services architecture requires "as a MUST" D3.0 in both sides HE and Home Network, it is possible to have CM < D3.0 connected in the same SG but, they must not be used to deploy Linear TV based on Multicast[15].

DOCSIS® 3.0 introduces the Downstream Service Identifier (DSID), this is a variable of 20-bit length that is embedded in the Downstream Service Extended Header of all packets that belong to a downstream bonded service flow and/or a multicast group service flow. The CMTS tags all the multicast packets with destination to same multicast group with a same value in the Downstream Services ID (DSID), from CMs point of view, they use the same tag to enable or not the multicast forwarding. This is a variable of 20-bit length that is embedded in the Downstream Service Extended Header. So, for multicast forwarding, in the CMTS MUST be configured the MAC domain as "Multicast DSID Forwarding" (MDF). The CM declares itself that it has MDF capabilities in the registration request messages, and the CMTS answers that the MAC domain, where this CM is connected, has MDF configured using the registration response message.

[14] The scope of this document does not include explanation of multicast over GPON because the limitations on the document length.
[15] Nowadays the networks of the company are completely in D3.0 and it partially updated to D3.1, D2.0 CM are being withdrawn.

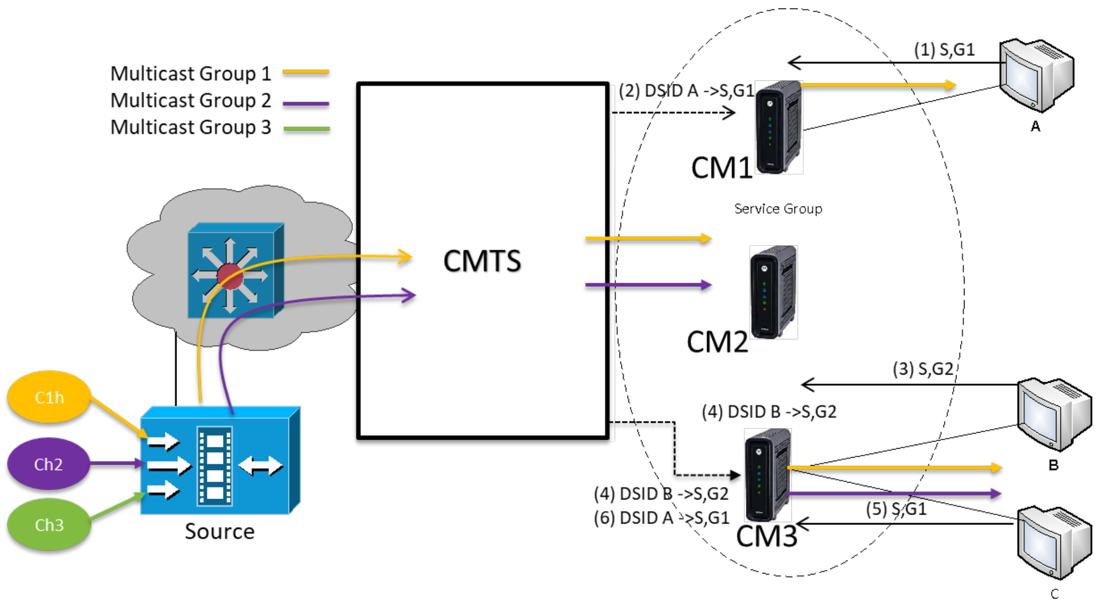


Figure 30 – Example of Multicast Forwarding in DOCSIS 3.0.

Multicast client protocol signaling (IGMPv3) is used for the clients (in this case the STBs) to join and to leave dynamically to the multicast group streams (Multicast Group Session).

The CMTS replicates the multicast traffic in the MAC domain in the set of channels that are called Downstream Channel Set (DCS) which is an identifier of a single Downstream Channel or Downstream Bonding Group (DBG). The CMTS replicates the Multicast traffic, which receives at the network side, towards the MAC Domain using those DCS, obviously, in D3.0 they are based in DBG.

In the Figure 30 a home device (which could be an IP STB) subscribes the channel 1 (Ch1) using a Join to (S, G1), this message goes through the CM transparently and it is received by the CMTS. If the CMTS does not have the multicast traffic, it requests it to the network, then CMTS will receive the multicast traffic and it will replicate this traffic to the DOCSIS MAC domain (cable side) in a DCS (which is a DBG) using the DSID A, following this, CMTS will signal to the CM1 with DSID A and add the client mac address, using a Downstream Bonding Change Request (DBC-REQ) to inform it to read the BDG where the multicast traffic is replicated, and then CM1 forwards the traffic (S,G1) to end device that had requested originally the channel 1. It can see that the CM1 use the DSID as a filter to know which multicast traffic must forward or not to its Ethernet LAN ports.

Following with the Figure 30 explanation, when a devices B connected to the CM 3 asks for a channel 2, the same process happens (it will use a new DSID B) and the device B receives the multicast G2. At this point, in the DOCSIS mac domain there are two multicast streams present, Finally the device C connected to the same CM3 and it subscribes the Ch1, but it had been requested by device A in CM 1, so the multicast is already in the MAC domain, thus in this case, the CMTS just inform the DSID A to CM3, the client mac address and then it forwards the traffic to its LAN.

If some device, for example Device C, change the TV channel, this results in the CM 3 LEAVE the old Ch1 and JOIN the new channel. Then, again CMTS signals to the CM 3 using a DOCSIS MAC Management Dynamic Bonding Change transaction to create/change/delete the parameters necessaries for the CM to Leave the Ch1 and to join the new channel. Is important to note that is necessary for the CM always generates the "LEAVE" message because the CM has a limited number of bonded multicast DSID. The CMTS oversees signaling and add/change or delete the DSID and the client MAC.

5.3.2. Multicast Channels – Dedicated, Shared or combination of both.

The DOCSIS channels (QAMs[16]) used to transport the multicast traffic can be dedicated or shared by another kind of traffic. Figure 31 (A) and (B) show scenarios for dedicated and share QAMs respectively.

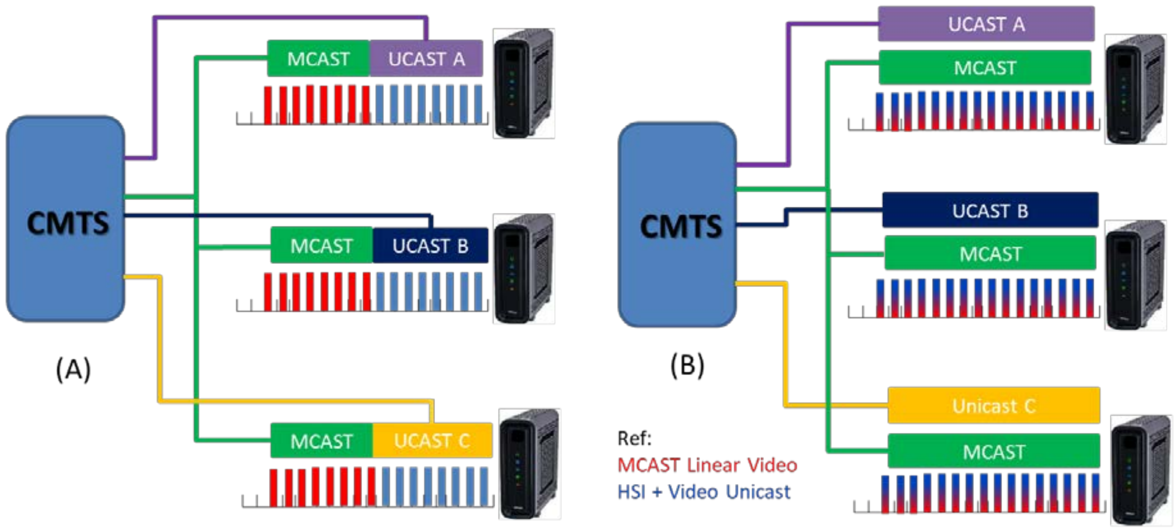


Figure 31 – Dedicated or Share QAMs for Multicast

The advantages of dedicated QAMs is that in those scenarios the Linear Video traffic in multicast is physically isolated from the rest of the other services, that could simplify the capacity planning of the services group associated with multicast, because the only traffic that they carrier is the multicast traffic for the Linear video (of most popular channels), and thus it be able to calculate and track the usage of those recourses in a simple way. In the same way, other advantages that could appear in this case is that, because the services are very well divided into different QAMs, it could be: the troubleshooting, the monitoring of those resources.

Contrarily, the advantages of shared QAMs is that the resources in term of bandwidth on the service group are better utilized during the beginning of the IPTV deployment. The video traffic will not be too much, let's remember that multicast video traffic it is a function of the number of channels in the lineup but also the number of the devices. Thus, to use dedicated carriers for multicast would mean a waste of the available spectrum. On the other side, because the statistical behavior of the data, the most efficient architecture is to share the channels between unicast and multicast traffic. If the sizing of the network is done in a correct way, resources are better utilized. But it is not ruled out to use dedicated carriers for a future, when the traffic will be greater and there is a better knowledge regarding planning.

The architecture's recommendations is to use a combination of both as it can see in next point.

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[16] The document uses the term of DOCSIS channel or QAM indistinctly.

5.3.3. CM Capabilities and channel assignment to CMs.

Regarding the configuration, the way to handle multicast video and data through the carriers is by configuring the DOCSIS service flow attribute mask[17] in the corresponding downstream and bonding groups. Each service flow creation request attribute masks (Required or Forbidden) may be defined as part of a provisioned service class on the CMTS. Every channel and bonding groups have a resource attribute mask denoting the capabilities of that resource. This resource attribute mask is compared to the attribute masks of the service flow request provisioned in the service class. The CMTS attempts to assign service flows to channels or bonding groups such that all required attributes are present and no forbidden attributes are present, doing that is possible to match what kind of traffic must be carried by which downstream groups of channels (DBC).

Besides this, there are different kind of CM with a different number of tuners already deployed in the network: D3.0 4x4, 8x8, 16x4, 24x4, 24x8 and D3.1 32x8 + 1 OFMD Block. This diversity could generate an extra issue for capacity planning because depending on the combination of the amount of the channels used for the DOCSIS SG and the CM's capabilities (number of tuners) it could be necessary to replicate several times the same multicast group traffic in the same SG. Figure 32 depicts this case where it is necessary to generate 3 different multicast streams that are using a different DCS in the same SG, which means a decrement in the multicast gain.

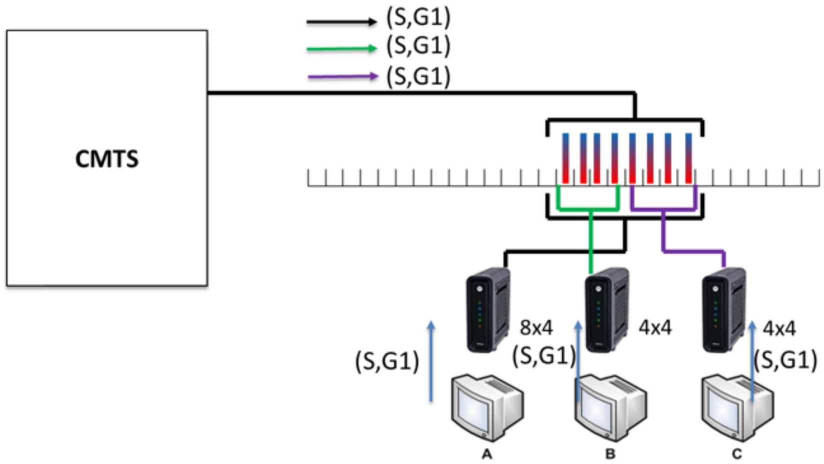

Figure 32 – Decrement of Multicast Gain because of diversity in CM capabilities.

It must be mentioned that inside the home network, as it will discuss in the next section, the Customer Premise Equipment (CPE) is no simple CMs, but it is EROUTERs, which means that it embeds in the same CPE a CM but also Residential Gateway (RGW) functions that must meet with multicast distribution inside the Home. The last ones have to be prepared to accept and distribute the multicast data inside the home network. Thus, even when the D3.0 CM is used by the EROUTER could manage the multicast according to the specification, the internal RGW could not work properly with multicast. This point could be fixed with software upgrades, but if apart from that it is necessary to have strong WiFi capabilities to distribute the video, it is very probably that old EROUTERs, already deployed in the field, could not support the video service distribution as a managed service.

[17] This paper (26) explains in the detail the usage of this attribute

Given this point and the aforementioned issue regarding the diversity of CM capabilities, the architecture decision was to deploy the IPTV services using the last EROUTERS generation and the next ones, with D3.0 CMs 24x4/8 already in deployment or next ones D3.1 CMs 32x8 + N x OFDM blocks[18].

Another definition is that to provide IPTV services the SG size must be at least 24 D3.0 channels. However, in the future will be possible to extend the SG to 32 D3.0 channels, and to add D3.1 OFDM blocks. When that will happen, it will have to be careful with the already deployed CMs with 24 SC-QAM. Because the SG will have 32 SC-QAM, the CMs with 24 SC-QAM will have more than one set of QAM to register. In this scenario, to avoid having multiple multicast streams in the same SG, we MUST use static bonding group.

To maximize the multicast benefit (and minimize bandwidth) on the service group, the decision is to distribute the multicast on a set of 24 Single Carrier-QAM (SC-QAM) fixed in the spectrum but sharing this QAMs with the other services (HSI, telephony and Unicast Video). The way to define which are the 24 channels that will transport the multicast traffic is based in the Attribute Mask defined in DOCSIS (11).

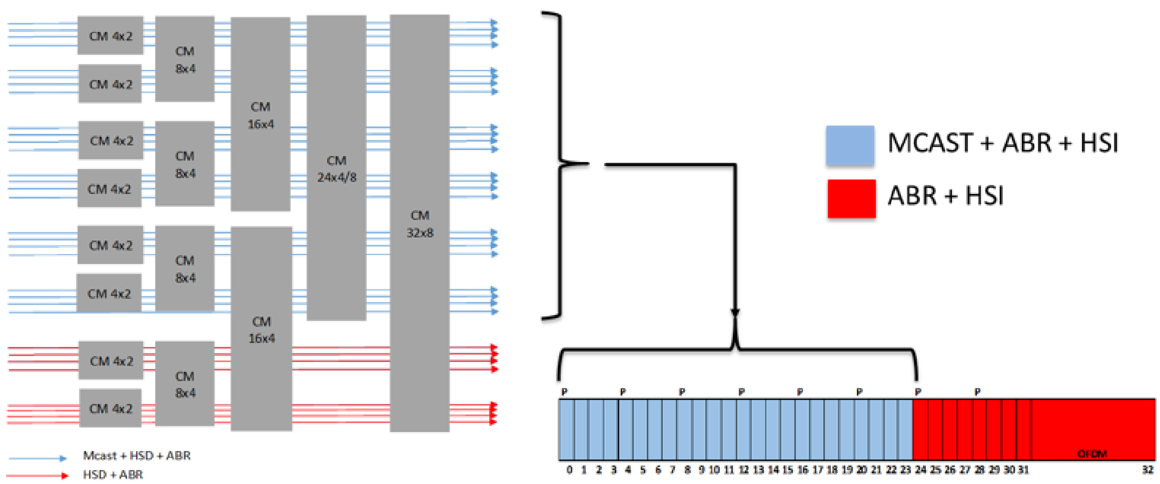

Figure 33 – Multicast distribution in the Service Group

As it was mentioned, when the SG is extended from 24 to 32 channels it is possible that 24x4/8 CMs could have different combinations of channel bonding (same happens with 4x2, 8x4, and 16x4). To assure which must be the group of channels in the SG, that must be used to connect CM with different capabilities, the bonding groups must be defined statically, and all the static bonding group with more than 24 QAMs MUST include de multicast bonding group.

Thus, defining where the CMs must bond the channels, with the static bonding configurations, and establishing which must be the channels that carriers' multicast using the Attribute Mask, the multicast traffic will be distributed across only one possible set of channels in the SG for the D3.0 24x4/8 or D3.1 CMs.

Figure 33 shows this configuration. It depicts the distinct set of bonding arranges, where modems with different capabilities will use a diverse set of those BG. Particularly there is only one BG of 24 SC-QAM

[18] In this deployment, CMs (and home gateways) that are used for the IP video service MUST be capable of receiving at least twenty-four SC-QAM downstream channels (independently of how many channels are used for multicast traffic).

where the D3.0 24x4/8 CMs can be registered. The Linear TV multicast is enforced to use the same channels that are based on the Attribute Mask but they are also used for HSI and Unicast ABR. Contrarily the additional capacity (the red one) must be used just for unicast: HSI, ABR video, telephony or other. The first 24 channels (the blue ones) are shared form Multicast and Unicast while the other 8 channels plus the OFDM block (the red ones) are used only for Unicast.

The picture shows channels with a "P" indicator, that is because those SC-QAM are primary channels, that are necessary because in the network there are CMs with 4x2 capabilities, so it must have one primary channel in each bonding group. Also, even today in our network there are some DOCSIS 2.0 CMs, and it needs a primary channel for those CMs. Using secondary channels instead of the primary could save some Mbps capacity per channel.

5.3.4. Uncorrected error and Partial Services - Multicast Resiliency in DOCSIS Networks

Figure 34 shows an SG with CMs that are consuming regular unicast data and joining to a multicast group. If, for example, there´s a problem in CM 2 with 2 QAM channels, it reports the problem to the CMTS and the CMTS declares Partial Service (PS) for this CM.

The CMTS sends the Unicast Traffic spreading the unicast data (that is different for each CM) through all QAM, except for the CM 2. In this case, the CMTS sends the data for this particular CM avoiding using those channels that for this CM have an issue.

However, for Multicast Traffic, the CMTS continues sending the data through all QAM channels (because the Multicast traffic for this Multicast group is the same for all CMs connected to this SG), so the portion of data carried by the QAMs, that CM2 is detecting errors, has uncorrectable errors and then the application that uses that data doesn't work (video is broken).

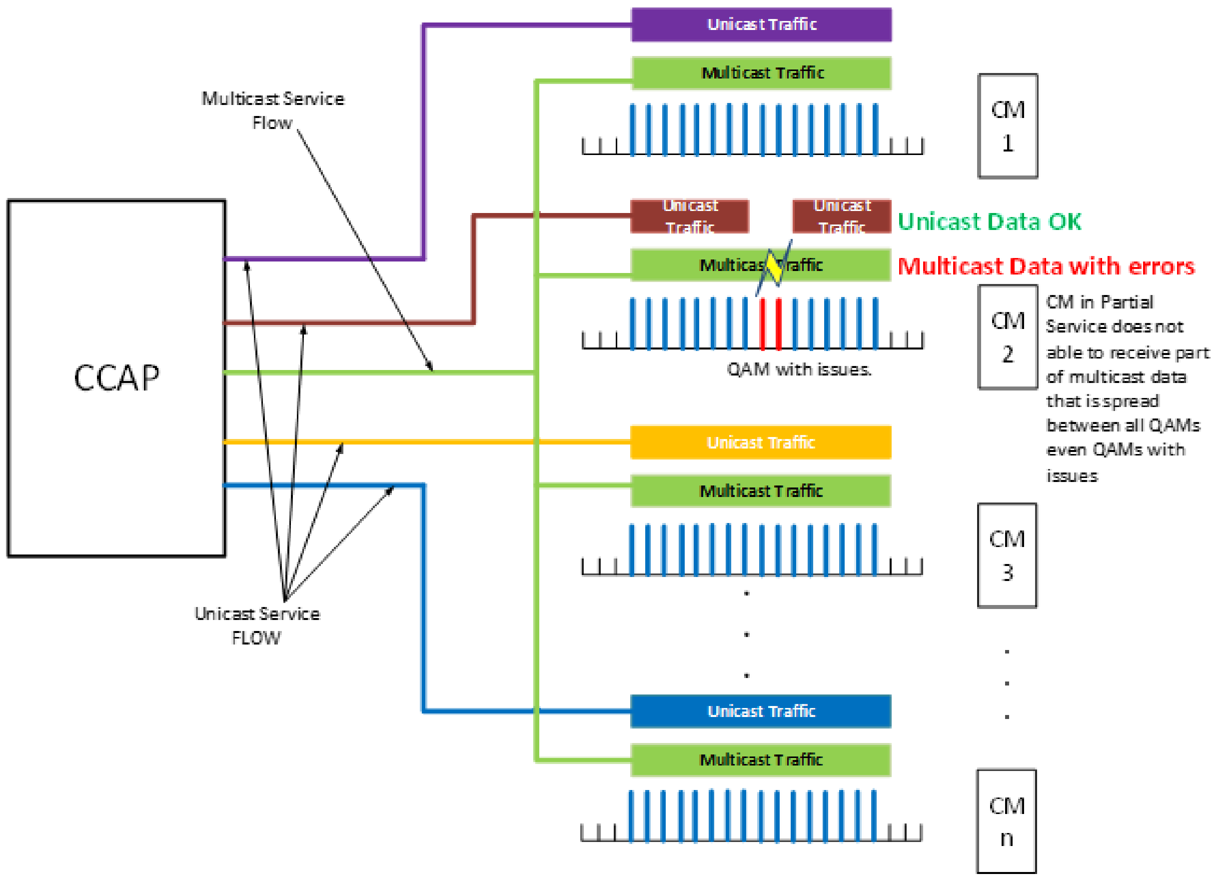

Figure 34 - Multicast Traffic issues due to Partial Service

Figure 35 is a diagram that shows the sum of CM's channels with a Partial Service mode declared in the CMTS for the whole network, a give CM could have Partial Service in more than one channel. There are around 17% of CM with PS, which means that all of them will have problems with video over multicast. The root cause is ingress noise that is generating in home networks but also in HFC network, for instance, frequencies in the range of 759-777 MHz come from mobile networks (LTE).

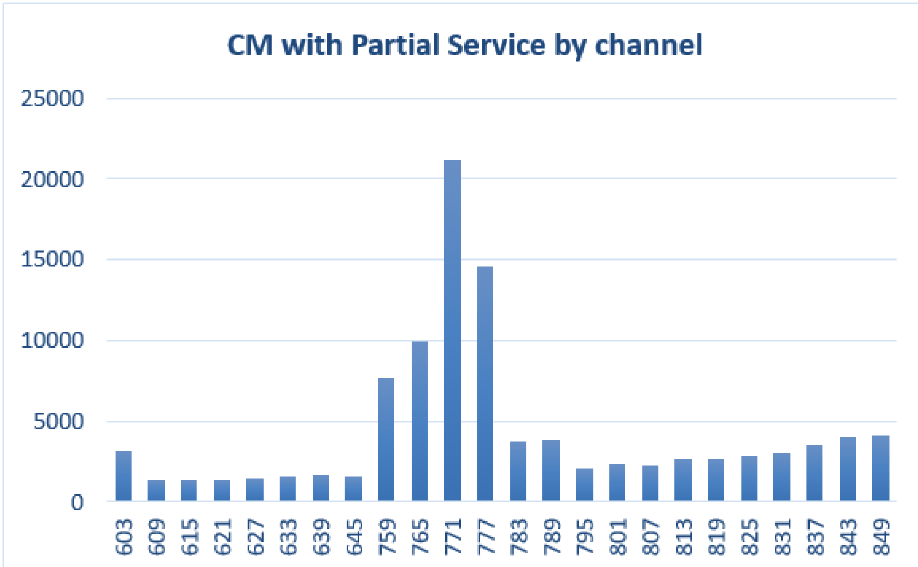

Figure 35 – CM's channels in Partial Service Mode per frequency[19].

If it avoids using the channels in the range 759-777 MHz, which are the most affected, then it could reduce the CM's affected up to 6%. To do that it is necessary to reconfigure the arrange of channels used for Multicast used in the Figure 33 and reconfigure according to Figure 36.

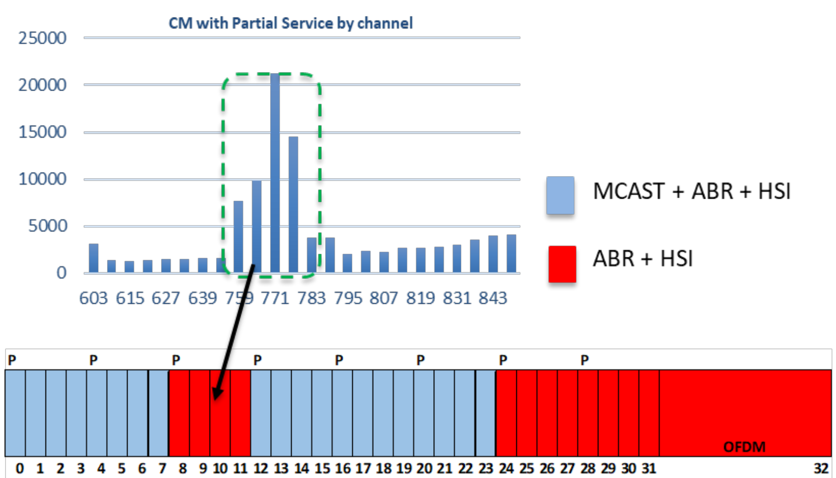

Figure 36 – Reconfiguration of channels for Multicast to reduce Video Issues per PS.

However, even when the number of CMs with these problems are low in relative numbers, in absolute numbers means a big amount of client with video issues in the most popular channels distributed with multicast. It must be considered that in legacy digital TV, if some frequency has problems (noise, etc.), just the signals carried by this frequency are affected, but here in IP multicast, all the signals will have problems because the data is spread over several carriers. Again, those ingress noise must be fixed with

[19] Note that these statistic numbers are the best case of the issue presented here, since there are many CMs that don´t an entry in partial service mode and still have the problem, that simply happens when there are uncorrected errors in some carriers.

maintenance, but even doing those operation tasks, the ingress noise could appear in any moment and in any part of the spectrum/network. This case should be considered not only from operational but also from a technological point of view, to do multicast in DOCSIS more resilient against these kinds of problems. The solution/s must be dynamic avoiding the necessity of operator's intervention and preventing the most as possible a complete blackout in the lineup for those clients behind a CM in PS mode. Following, four different mechanisms to reduce this effect.

Option 1: Multicast Resiliency by Capacity reduction of Multicast SG.

This method decreases the capacity of Multicast SG to avoid issues in CMs with Partial Service Mode. When a given number of CMs in a service group enter in partial service mode for a QAM channel, the CMTS stop sending multicast in that QAM channel. The number of CMs MUST be configurable starting at 1.

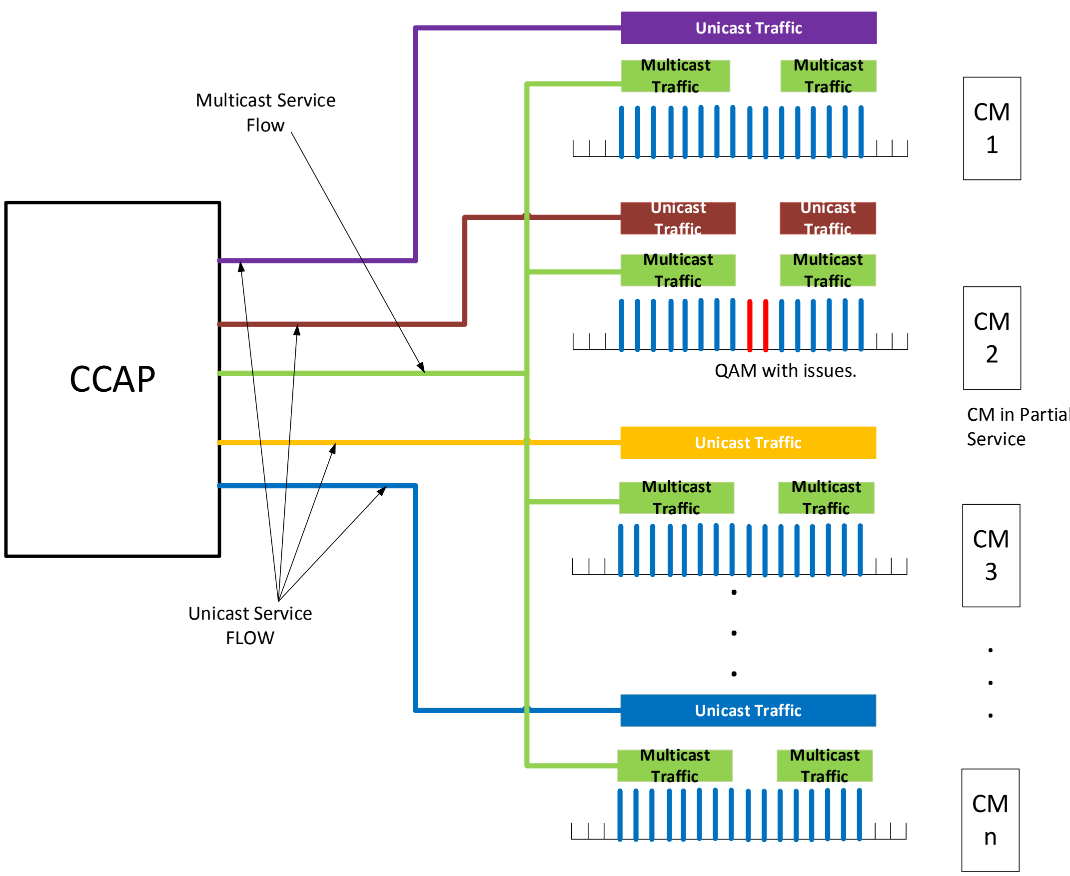

Figure 37- Multicast Resiliency by Capacity reduction of Multicast SG.

CMTS is who decides what QAM channel must be excluded or included dynamically in the Multicast SG based on the settings. The decision to include/exclude a given QAM channel in/from a Multicast SG depend on the amount of CM with Partial Service because of this particular QAM channel. The maximum number of QAM channels that can be eliminated from the "multicast bonding group" MUST also be configurable to avoid congestion problems in the SG because of the QAM reduction. There must be a configurable threshold level/timer before the decision to exclude a QAM channel from the Multicast SG. There must be a configurable threshold level/timer after the decision to include a QAM channel again in the Multicast SG.

Option 2: Multicast Resiliency by Multicast to Unicast in CM with Partial Service

This method does not modify the Multicast SG capacity for CM without problems, but for CMs that are in Partial Service, the CMTS will send the same data that should be carried using Multicast but using Unicast. This mechanism could affect the SG sizing.

When a given CM enter in partial service mode for any QAM channel, the CMTS stops sending multicast for that CM and convert the Multicast traffic that came from network side interface to Unicast in DOCSIS SG.

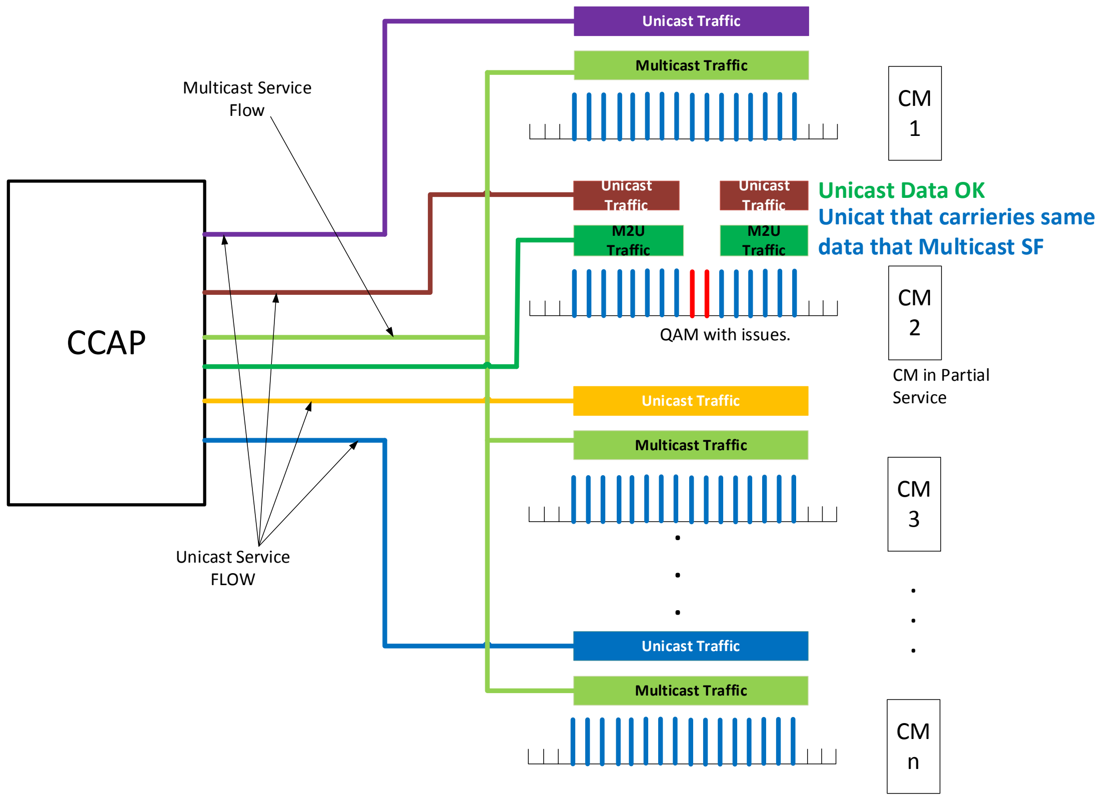

Figure 38 - Multicast Resiliency by Multicast to Unicast in CM with Partial Service.

CMTS is who decides what CM will receive a Multicast 2 Unicast (M2U) traffic instead of Multicast. There must be a configurable limit of CMs that could receive M2U traffic for a given SG. This is to avoid the congestion of an SG because of an excessive amount of CMs that are in PS and then a huge amount of M2U traffic that generates a congestion of the SG which sizing was done considering Multicast traffic.

It should be also possible to configure at the CMTS level that for a given Multicast Group, that, for instance, transports high audience video signals, the CMTS never generate the M2U mechanism.

The decision to change from Multicast to M2U is just the based on the Partial Service mode detection for a given CM. There MUST be a configurable timer before deciding the change to M2U.

The CMTS should come back from M2U to Multicast when for a specific CM that was working in Partial Service Mode it works again normally. Before deciding to go to Multicast it is necessary to wait sometime, this timer MUST be configurable in the CMTS.

Option 3: Multicast Resiliency Hybrid

To improve the amount of networks resources used we can combine Option 1 with Option 2. For a configurable number of CMs the CMTS uses M2U (option 2) and if that number is exceeded the CMTS starts forwarding the traffic to all CM in a reduced bonding using multicast as is explained in option 1.

Option 4: Multicast to Unicast based on STB and BO interaction

In this case the solution it is not based on the DOCSIS itself but is based on the interaction between the STB and the BO of the system. As was mentioned at the beginning of this section, Unicast traffic is not affected by the PS because DOCSIS manage that in a perfect way. So, it could be possible to generate a mechanism to detect the video impairments on the STB and based on that to request a unicast ABR video instead of multicast. Because the amount of the CMs with PS in an SG is small, it is possible to use Unicast ABR instead of Multicast for those CMs with Issues. This mechanic must be generated at control plane level between the STB and BO and could be a proprietary solution.

5.3.5. Video QoS for Unicast and Multicast.

DOCSIS® uses a shared medium but it provides tools to ensure QoS. To differentiate the QoS of video services over DOCSIS the ecosystem must be configured to carrier those data over specifics Service Flows (SFs). That configuration must consider the QoS not only for the media and for the control plane, and the last one includes the communication with the BO. The Figure 37 shows conceptually which are the different kind of traffic that must be managed. They are:

1. Unicast Video to connect Managed STB with CDN, over this it is delivered CoD and lowest popular Linear TV signals.
2. Multicast Video which carrier the most popular Linear programs to STBs.
3. BO control that is used to manage and signal the video services in any device.
4. HSI data access that is used to connect the general Home network devices with internet. This is also used to carry the video the Unmanaged Devices like Tablet, Smartphones, PC, etc., in this case even when the video come from the CDN, the product business case indicates that those devices must share the resources with HSI access.
5. IGMP message generated by the IP STBs (they are not depicted in Figure 39, to see Figure 40)

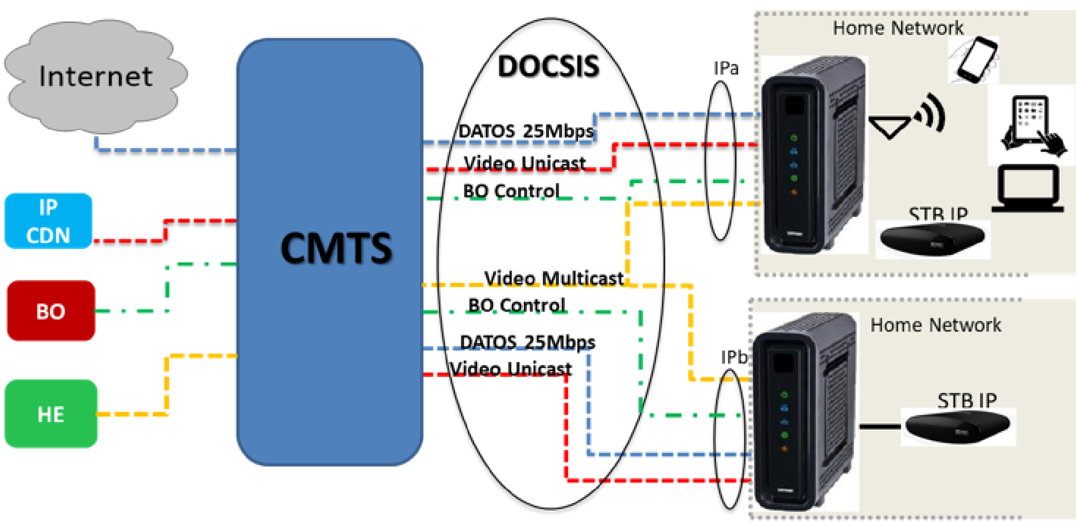

Figure 39 - Different kinds of traffic in DOCSIS

The Unicast Services Flows are based on DOCSIS Classifiers that are configured in the configuration file of CM. The Service Flow provide the QoS Parameters for treatment of those packets on DOCSIS. A Classifier is a set of criteria applied to each packet, which consists of some packet matching criteria, (destination IP address, for example) and a classifier priority. If a packet matches the specified packet matching criteria, it is then delivered on the referenced service flow. The classifiers could be based on Source: MAC Address, IP, Port; Destination: MAC Address, IP, Port; protocol, IP TOS/DSCP, 802.1Q VLAN ID.

It could use classifiers base on IP address, but if for instance the CDN is distributed and the IP address of those elements are not in the same IP segment, the configuration file must have several classifiers, and then it could be more complex in terms of operative and maintenance tasks, because every time that a new CDN node is added in the system the Classifiers must be modified. On the other hand, to use IPs and Port as filters in the classifiers do not allow to differentiate the Video Unicast traffic for Managed (STBs) and Unmanaged (OTT) devices, and the rule number 4 aforementioned is not fulfilled.

So instead of used IP:Port the classifier could be done based on DSCP, and then it is possible to use just one classifier per service flow and even when the operator will modify the CDN topology, or BO or HE configuration, the classifiers in the CM's configurations files are kept.

At the same time if the CDN could mark with different DSCP based on the User – Agents (of the devices) that generate the content request, then it should be possible to mark with a given DSCP the traffic from the CDN towards STBs and with other one towards OTT devices (with other or directly without DSCP mark). In this way, the traffic from CDN towards managed devices is carried on a specific service flow, but from the CDN to unmanaged devices is treated as a regular internet traffic and it goes in the HSI services flow.

It is important to note that the Service Flows are Unidirectional, and the classifiers must be configured in both ways, downstream and upstream. All of them have defined a set of QoS Parameter: all are Best-Effort Service Flows but they are differentiated between them with, Maximum Sustained Traffic Rate, Maximum Traffic Burst, Minimum Reserved Traffic Rate, and Traffic Priority, that are configured in each one. That can be appreciated in Figure 40 (the priority is showed as P: x in each service flow).

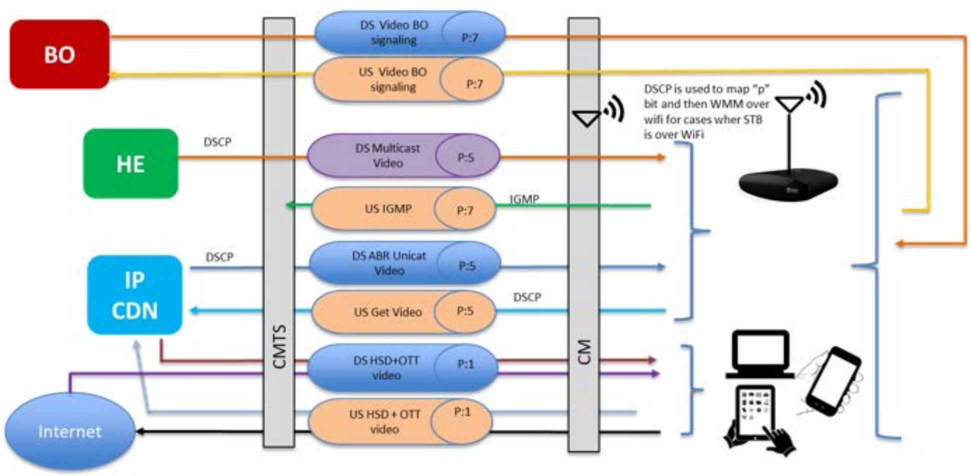

Figure 40 – Service Flow Configuration

It should be possible to combine some of those services flows, for instance in the Figure 40, US Get Video, US IGMP and US Video BO signaling, could be potentially managed in only one "Signaling" service flow, but the separation could be used to get statics on each service flow, for instance using IPDR, and because this is a starting deployment, it could be configured in this way and when the operator get experience then move to a simpler configuration.

Unlike Unicast, the Multicast traffic is not based on the CM's configuration file but is based on Service Class Names (SCN) rules that are configured at CMTS level, that mandatory to work with Multicast as was required in this document. To set up QoS for multicast some definitions are required:

- Multicast Groups QoS: each multicast group segment address can be assigned at different Service Class Name, thus if it is required to apply different QoS parameters to a different kind of content, like SD, HD, UHD, (or other categorization), then it could be possible to represent those content types with diverse set of IP multicast segment address and then to apply different SCN. That is defined in a "container" that as is showed in Figure 41.
- Service Class Name: here is where the service flows are defined, once the Multicast Group QoS is defined, it is associated with SCN, also another set of QoS parameters are assigned:
  - Direction: Upstream (1) or Downstream (2) (for multicast is 2)
  - Attribute Mask: this is the value that is used to match with the DOCSIS channels defined in the BG which will carry the multicast traffic. The attribute mask can be: 1) required and in this case the CMTS will use BG with this bit marked it their associated channels attribute, or 2) forbidden which is the contrary.
  - Maximum Sustained Traffic Rate/ Maximum Traffic Burst / Minimum Reserved Traffic: this are the same parameters that must be configured in a service flows on CM's configuration file, with those parameters is possible to configure the video's bit rate profiles assigned at each type of video stream, for example 2Mbps for SD, 5Mbps for HD, 20Mbps for UHD (or other depending on the chosen criteria in the Multicast Groups QoS definition)
  - Priority: this the priority's Service Flow parameter, that is used by the scheduler to give more (higher number) or less (lower number) priority to the traffic that is transported in this Service Flow when it compares with others.

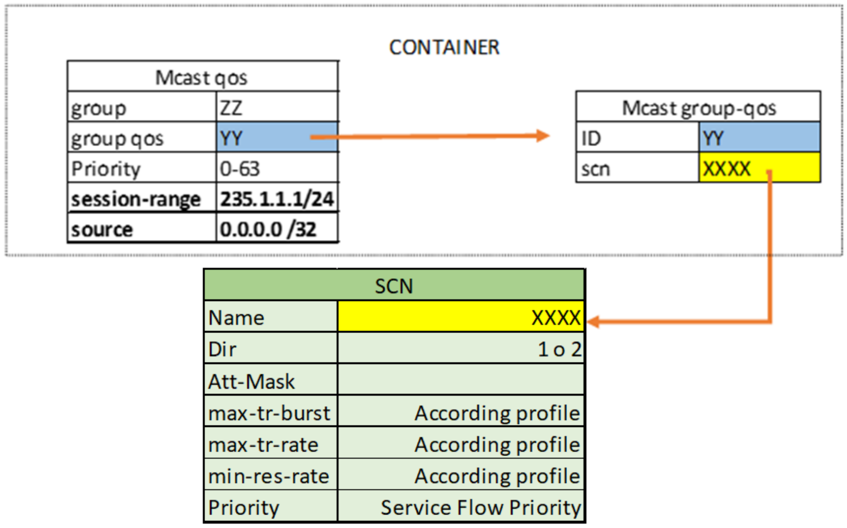

Figure 41 – SCN definition.

In order to protect the amount of multicast session that a given CM can subscribe it is recommendable to set maximum multicast sessions that a CM can join at the same time. The CMTS keeps the tracking of the multicast session for each client and limiting the number of multicast session behind a CM could prevent a denial of service attack. That is also part of the DOCSIS® specification (11).

Finally, in some CMTS it is possible to configure a Connection Admission Control (CAC) to limit the capacity used by multicast in the channels when this capability is configured just a percentage of the channel will be used for multicast. When the CMTS receives a JOIN message it is checked if there is enough capacity to allocate resources in the BG based on the Minimum Reserved Traffic, if there is no capacity then the new Service Flows it is not admitted.

5.4. Home Network

Finally, it is the Home Network (HN) domain, and this is maybe the hardest changes needed to move to Full IP Video, and not because of the technology itself, but because of the change of the paradigm for the operator and the end user.

Figure 42 compares the today model with the Hybrid HN (A) against the Full IP HN (B). The main difference is the change of the way that STB is connected. In the Hybrid HN, even when the UX experience could generate a disruptive change in the client's way to consume the service, because the new advance services, new UI, and others that were mentioned at the beginning of this document, the Hybrid STB is still installed and connected in the same way that a Legacy DTV STB. The technicians are still using the same tools and process, the connection inside of the HN is based on COAX. In the new Full IP HN the STB is connected in the same Ethernet network that is provided by the EROUTER's LAN, so the technician's "COAX's toolbox" does not work any longer. The IP STB is connected with Unshielded Twisted Pair (UTP) patch cords, WiFi, or even more through LAN device extensors, like Power Line Communications (PLC) or WiFi extenders.

So, the technician must add to their COAX's tools, Ethernet tools, UTP cable, with tools to check the WiFi connectivity and fix it in cases where the coverage it is not enough, the new devices as aforementioned PLC or WiFi extenders must be part of the devices in the technician's trucks just in case of need in the installation. It could appear complications, for instance, the EROUTER has in general four Ethernet Ports, but all of them could be used at the installation moment, then the installation must be done using just WiFi, or connecting a local LAN Switch.

Those apparently simple facts imply new process in the installation, new skills for the technicians and several modifications in the MSO's Operations Support System and Business Support System. So, an IP STB installation is not a just a traditional TV services installation, it is really a Home Network Installation, wherein some cases it could be as simple as connect a STB to the WiFi HN, or it could be as complicated as whole Home Network installation to support the TV services.

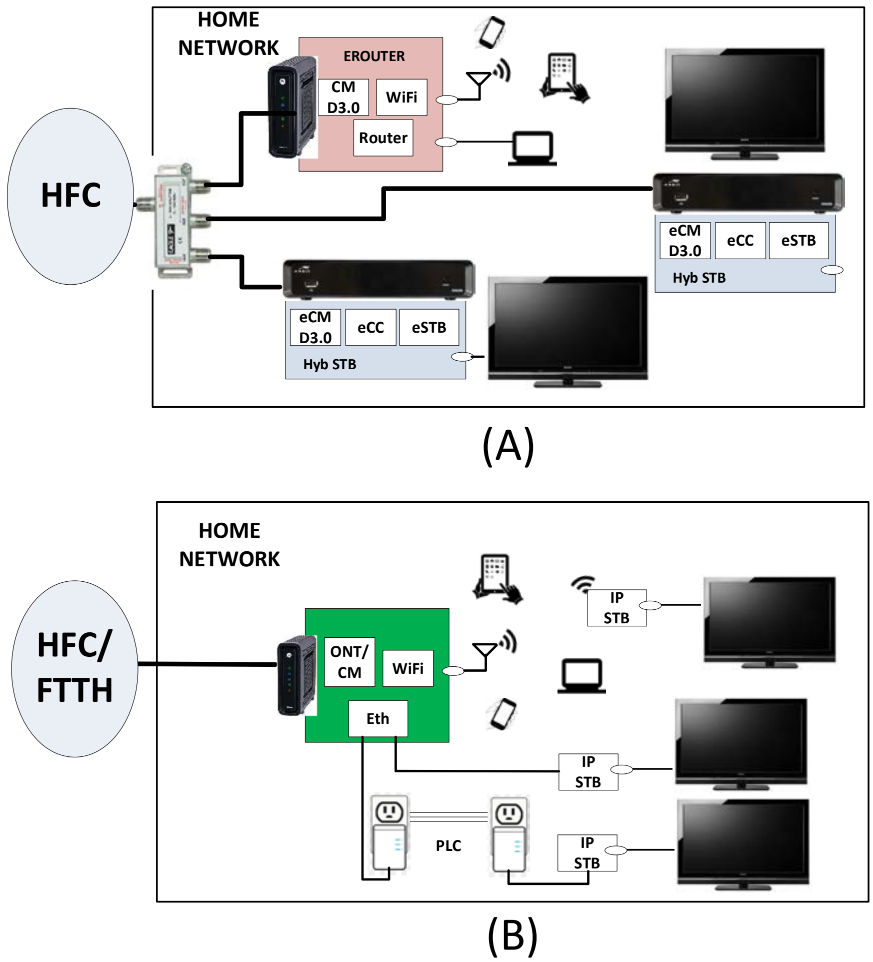

Figure 42 – Hybrid Home Network (A) vs Full IP Home Network (B).

Nevertheless, there is a lot of numbers of improvements and benefits, for the operator and the end client:

- The first one that it can be appreciated is that there is just one CM per home, then when in the Hybrid HN at least 2 CMs are required per home, one for the HSI and another one for at least 1 STB, so if every client in the DOCSIS SG has HSI and TV services with the Full IP home network the SG size is reduced in at least 50% of CM (in general there are 2.5 TV sets per home).
- At the same time there a cost reduction in terms of the STB's cost, the Hybrid STB has an embedded CM which means an extra cost per each TV.

- In the Hybrid HN, there are multiple points of the operator's HFC network entering to the client's house. In the Full IP HN, there is just one, and that is a demarcation point, it separates the operator's network. This demarcation isolates the ingress noise that could be produced inside the HN in the traditional COAX connections inside the client's house. That could generate a very good impact on the network operator in terms of maintenance and improvement in the QoS of the network.
- The Home Network model it is the same for DOCSIS or for xPON access networks, obviously the CPE will be deferent, EROUTERS vs ONT with embedded RWGs, however the RGW itself of both must have the same capabilities and functions, and the IP STB is agnostics to any of those access networks, even more, the TV service installation could be almost the same process, it is the same for booth access network.
- Even with the installation complications, that were aforementioned, the WiFi capabilities of the EROUTER/ONTs and IP STBs should be enough to cover most the homes, and with the help of an installation guide implemented in the STB, that could be shown during the first installation of the STB, it could mean the first steps towards an auto-installation, which means more cost savings.

From the LAN point of view, the capabilities must be the same for any CPE D3.0, D3.1 or xPON. For instance, the Figure 44 and Figure 45 are the minimum hardware reference architecture for the CM Residential Gateway for D3.0 and D3.1 respectively. The CPE is a device compliant with eDOCSIS specification (12), it includes an embedded D3.0 or D3.1 CM (eCM). Regarding the WiFi capabilities, the minimum requirements is a Dual Band Concurrent WiFi Radios in 2.4Ghz and other in 5Ghz, with the support of 802.11n (13) and 802.11ac (14) (wave 1/2). The antennas' arrangements are 3x3:3 for 2.4Ghz and 4x4:4 in 5Ghz. The CPE supports IPv4, IPv6 and Dual-Stack IPv4 and IPv6, but the video service up now only supports IPv4, thus the rest of the requirement explained here are based on IPv4.

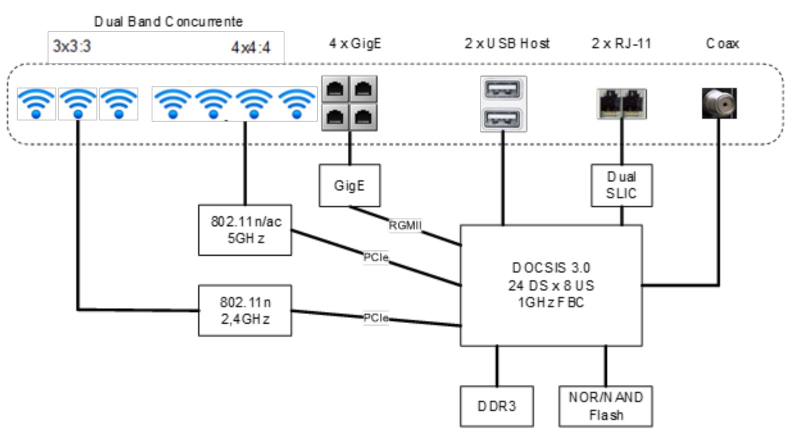

Figure 43- Cable Modem Residential Gateway WiFi D3.0 IPTV ready.

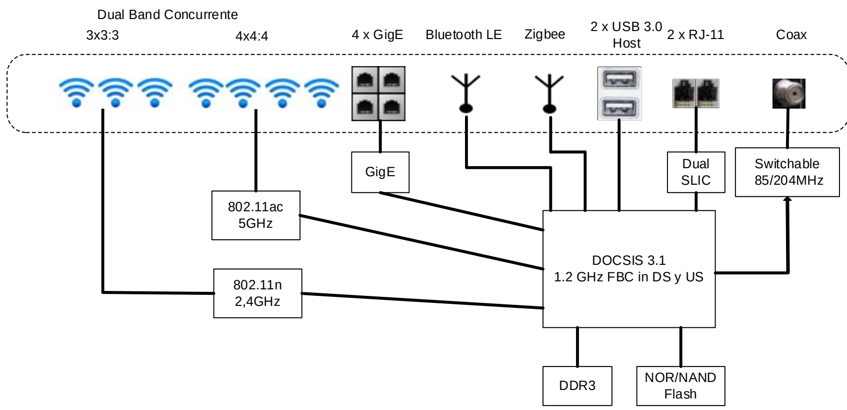

Figure 44 – Cable Modem Residential Gateway WiFi D3.1 IPTV ready.

Regarding the multicast frames forwarding the CPE must implement some specific functions (Figure 45):

- It must support IGMPv3 (10) in the Ethernet or WiFi interfaces.
- The internal LAN switch in the EROUTER must support IGMP Snooping (15) capabilities to forward the multicast frames only at the ports that have a connected device (receivers) that had requested a subscribe to a Multicast Group, and avoid sending multicast traffic to devices that are connected to the same LAN and have not request this data. In general, the tracking per-host membership status on an interface allows also to implement fast leaves, with this feature the switch can determinate when the last device (IP STB) sends an IGMP leave and it stops immediately to forward multicast traffic for this group.
- The LAN devices are not connected directly to the CMTS, who should receive the IGMP message transparently through the CM, in this case, the eCM. The IP STBs, same that other devices are connected to the access network using PAT, then the IGMP messages generated by STBs are not connected directly to the CM but to the internal router of the EROUTER. To manage that situation, the internal router must work as IGMP Proxy on behalf of IGMP messages generated form LAN devices. The internal router must keep the tracking of which device in the LAN requests IGMP messages and it resends those to the access network changing the host who generates the request by its WAN IP.
- When in same LAN there are devices working with IGMPv2 and IGMPv3, the router's local interface will receive IGMPv2 and IGMPv3 Membership reports, then when that happens, it will decide to do a fall back to IGMPv2, even when the router was configured to work with IGMPv3. If it is not possible to prevent IGMPv2 requests from devices other than an IP STB, then it could generate an issue when it is expected that the system works based on IGMPv3. To avoid that, the CPE must block the IGMPv2 message toward the internal router.
- Multicast over WiFi does not provide a good mechanism to guarantee the QoS of the all of IP STBs connected to the wireless LAN. When two or more devices are connected in a WiFi network they could place at different places in the HN, and then they could reach different bit rates based on the WiFi profiles that those devices can negotiate with the Access Point (AP). In such a case, the multicast packets, that must be just one stream for all the devices that have subscribed the same multicast group, and it will be forwarded with the lowest bit rate that can be reached by the device that has the worst situation in terms of WiFi. To avoid that the CPE must implement a Multicast to Unicast forwarding at the WiFi level. When multicast frames must be forwarded from the WAN interface to the WiFi segment, the MAC address Multicast Group it is replaced by the Unicast MAC address of the receiver that had subscribed to that Multicast group. Figure 45 shows how the CPE replace the multicast MAC address with host X's MAC address

when it forwards the multicast frame over the WiFi (which does not happen in the Ethernet segment).

- To avoid deny of service attacks the CPE must allow configuring a limit in the amount of the multicast session that could potentially be subscribed by devices behind the CPE. So, for instance, if the HN has 5 IP STB in each moment connected, it is not necessary to support more than 5 multicast groups. That could be configured with SNMP per device, and/or could be part of the CPE file configuration that is download during the registration, or it could be configured based on TR-069 (16) from the Automatic Configuration Server (ACS).
- An extra security mechanism that should be implemented is an IGMP messages threshold, after a given number of IGMP message per second the CPE should discard the IGMP messages, to avoid a waterfall of IGMP messages towards the access network.
- Another not mandatory but useful mechanism, it is to allow the operator to restrict which devices can subscribe to IPv4 specifics multicast groups used for the TV service. This is required to allow only STBs can subscribe to those multicast groups and it does not allow user devices to subscribe them to avoid attacks.

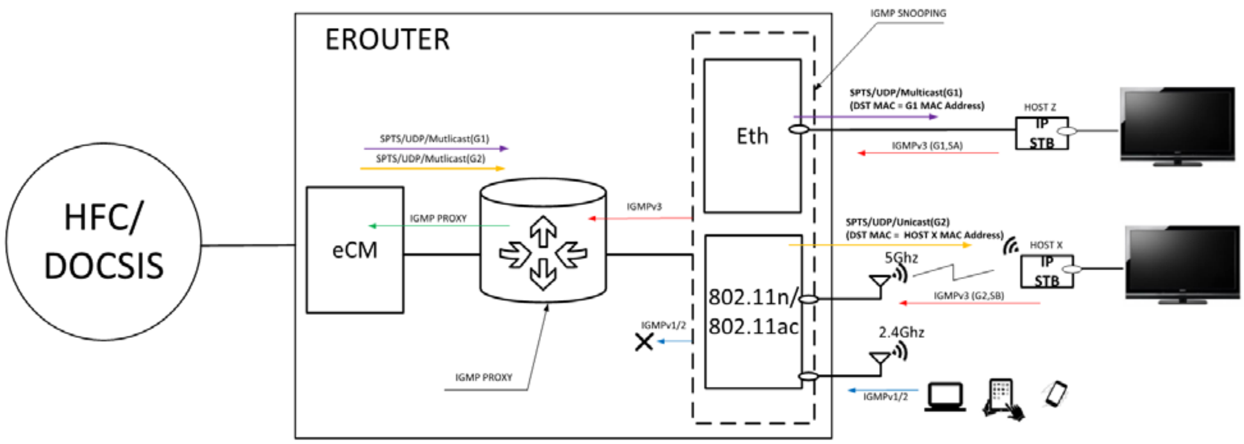

Figure 45 –Multicast Functions that CPE must implement.

The IP STB can be connected with Ethernet or WiFi, being Ethernet the first choice. But sometimes it is not possible to cabling the house because the technicians could find itself with objections from the client, installation time, etc.

The buildings are mainly located in urban areas with high population density and where the concurrence of Wi-Fi networks is consequently very high. If a network scan is made in any department within Buenos Aires city, it is difficult to find less than 20 networks within the 2.4GHz band. Added to this is the fact that these conditions are not constant but tend to vary over time.

The band of 5GHz first, it is a much less congested frequency, the number of networks that emit on this frequency is quite small, so the interference is much lower. Also, the coverage of this frequency is lower in distance than 2.4GHz, thus the potential interference problems are reduced.

In situations where cabling is not possible, and the connection is made through Wi-Fi, the STB IP must be connected only to the 5GHz network considering the signals levels. The levels reported by Received Signal Strength Indicator (RSSI) of the IP STB must be better than -60dBm. That level is verified in the IP STB's connection process and if the level is not reached then the STB will show on the screen a message indicating that WiFi conditions are not enough for the video service.

To guarantee the QoS in the WiFi it is used Wireless Multimedia (WMM) what is based in 802.11e (16). With this, the WiFi is prioritized according to dissimilar categories of data which is determined based on the "P" bit of 802.1p. Table 5 shows the mapping between the P bit and the data types. The P bit in the multicast packet is getting from the DSCP mark as can be appreciated in the Figure 40. The Figure 46 shows a capture of the WiFi traffic where the DSCP and then "P" bit is mapped correctly to the WMM category.

Table 5- WMM "P" bit mapping.

802.1p Priority	WMM Access Category
1	Background
2	
0	Best effort
3	
4	Video
5	
6	Voice
7	

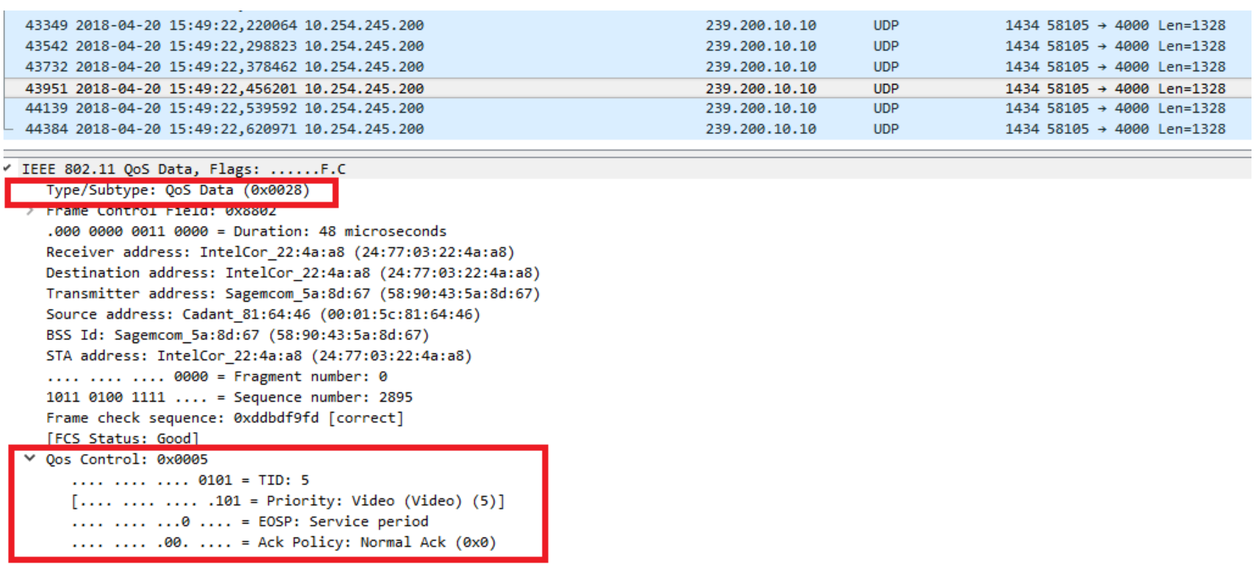

Figure 46 – WiFi Traffic capture with WMM.

Conclusion

There are several drivers to move towards Full IP video services, it is possible to get this objective in incremental steps. Move from legacy DTV system directly to Full IP system is very disruptive not only for the clients but also for the operators. The evolution of the TV services should be done in an agile way allowing the coexistence of legacy technologies with the new ones, and at the same time protecting the investment, giving the agility to speed up the deployment.

From the cable operators point of view the first step is to move to a Hybrid ecosystem, that allows providing a new UX to the end clients but keeping the robustness of the already deployed DTV services, and simultaneously generating new advance ways to consume TV, like better UI, TSTV functionalities, recommendations, and introducing new unmanaged devices like second screens.

There are two layers to evolve the ecosystem, the control plane, and the data plane; the first one is the main to introduce the changes in the UX and here is the first place where IP is needed, the second one is for the video distribution. For the Hybrid TV services, a new BO, new HE components, and a CDN are deployed. The control plane and media distribution for CoD and TSTV services as well as the second screen devices are based on IP. But most of the Live TV services are kept in DTV, which allows reusing the TV signals that are already in the HE, the transport of those signals through the networks does not change, in the access networks there are no changes, and even more important, the installation process of the TV services at the Home Network remains mostly like in the legacy DTV.

As it was mentioned at the beginning of this document, there are more necessities which must be covered, for instance: to deploy video services not only in HFC networks but also in other IP based access networks like xDSL, FTTH, Mobiles and in general other unmanaged networks; there are also better cost-effective STBs in the IP world and there are more vendors diversity. Another good point is that with IP STBs it is possible to have a more agnostic HN that could be connected in different access networks. Those drivers and the improvements in the technologies, like new video encodings, are facilitators in order to finally move from the Hybrid ecosystem to a Full IP Video.

It also was analyzed the linear TV audience behavior and the relation with the media transport mechanism. In small service areas with no more than 64 HHPP using unicast is it doable, but for a bigger size of HHPP to use only unicast for Linear TV could generate issues with the network capacity. Here is where Multicast helps, mainly for the most popular channels meanwhile unicast only for less popular ones (Figure 23) and CoD.

Finally, it was explained which would be the transformation to move from the Hybrid TV to the Full IP Video, starting in the HE, and then it goes through the transport and access networks where the main difference is the implementations of the multicast, and finally the HN where the transformation is visible not only for operator but also for the end client. It has been realized that Multicast over DOCSIS has some issues due to the ingress noise in the HFC plant or in the HN, and some improvements on DOCSIS side or in the video control plane are needed to provide a better resilient service.

For the future there are more improvements that it should be implemented, for instance, some of them are:

- It was mentioned that less popular Linear TV channels and the complete lineup for unmanaged devices, could be transported with ABR in Unicast delivery, however, there could be some constraints. There is a delay between the DTV and ABR signals which is around 20 to 40 secs (depending on the ABR's segments size, encodings, player buffer, etc.). This delay is not acceptable for the client point of view, especially for the specific type of content like live events or news. There are new technologies of Low Latency ABR that could improve that, for instance, Common Media Application Format (CMAF) (6).
- Another issue with ABR technologies are the subtitles for linear content, most of the content provider (at least in LATAM) provides Digital Video Broadcasting Subtitles (DVB-SUB) (17) which are Bitmap images that are not directly supported in ABR technologies, they support text

formats like Web Video Text Tracks (WebVTT) and others similar. There are mechanisms that use real-time Optical Character Recognition (OCR) that allows converting the subtitles images into text and then to generate the WebVTT. Also, the last versions of HLS and DASH allow also to use SMPTE-TT (18) embedding the images subtitles in base64 encoding, but for that new mechanisms must be implemented in OS at HE side and video Players in devices.

- Multicast is well supported in managed devices, but unmanaged devices do not support in general the Multicast, they use just Unicast ABR. That is not a big deal for small second screens at the moment, but it could be, again, an issue for the network sizing/planning when the operator starts to deploy the video services over smart TVs or Console Games in a massive manner because the audience behavior is like STBs (big screens). To address that there are new mechanisms that allow the delivery of ABR over Multicast, for instance, there are and CableLabs specifications (19) and a DVB draft (20).

As it could see in this document, the challenge to reach the objective is huge, not only for the changes in the technology but also for the changes in the skills of the operator which must deal with a new process in order to deliver the video in this new way, however this a new way that CSP must start to transit to address the clients and networks necessities, and finally to get the benefits of a real convergence.

Abbreviations

ABR	Adaptive Bit Rate
ACS	Automatic Configuration Server
AP	Access Point
ATS	Adaptive Transport Stream
BBIP	Backbone IP
BO	Video Back Office
CA	Conditional Access
CAC	Connection Admission Control
CBR	Constant Bit Rate
CDN	Content Delivery Network
cDVR	Cloud Based DVR
CE	Consumer Electronic
CM	Cablemodem
CMAF	Common Media Application Format
CMS	Content Management System
COAX	Coaxial Cable
CoD	Content on Demand
COTS	Commercial Off the Shelf
CPE	Customer Premises Equipment
CSP	Communication Service Provider
CuTV	Catchup TV
D3.0	DOCSIS 3.0

D3.1	DOCSIS 3.1
dB	Decibel
DBC-REQ	Downstream Bonding Change Request
DBG	Downstream Bonding Group
dBm	Decibel milliwatt
DCII	Motorola Digicipher II
DCS	Downstream Channel Set
DOCSIS	Data-Over-Cable Service Interface Specifications
DOCSIS	Data Over Cable Service Interface Specification
DOM	Document Object Model
DRM	Digital Rights Management
DSG	DOCSIS STB GATEWAY
DSID	Downstream Services ID
DSL	Digital Subscriber Line
DVB	Digital Video Broadcasting
DVB-SUB	DVB Subtitle
DVR	Digital Video Recorder
eCM	embedded CM
EPG	Electronic Program Guide
EQAM	Edge QAM
eSTB	Embedded Set Top Box
FHD	Full High Definition
FPS	Frames per second
GigE	Gigabit Ethernet
HD	High Definition
HE	Head End
HEVC	High Efficiency Video Coding
HHPP	Homes passed
HTTP	Hyper Text Transfer Protocol
HTTPs	Secure Hyper Text Transfer Protocol
IANA	Internet Assigned Number Authority
IC	Intermediate Cache
IEEE	Institute of Electrical and Electronics Engineers
IGMP	Internet Group Management Protocol
IP	Internet Protocol
IPTV	Internet Protocol Television
ISMV	IIS Smooth Streaming Media Video
LAN	Local Area Network
LTE	Long Term Evolution
Mbps	Megabits per second

MDF	Multicast DSID Forwarding
MHP	Multimedia Home Platform
MP4	Format created by the Moving Picture Experts Group (MPEG) as a multimedia container
MPEG	Moving Picture Experts Group
MSO	Multiservice Operator
NAPT	Network Address Port Translation
NAS	Network-attached storage
NAT	Network Address Translation
nDVR	Network Based DVR
nPLTV	Network Based Pause Live TV
OCAP	Openable Application Platform
OCR	Optical character recognition
OFDM	Orthogonal Frequency Division Multiplexing
OLT	Optical Line Termination
OOB	Out of Band
OTT	Over the Top
PAT	Port Address Translation
PC	Personal Computer
PHY	Physical
PIFF	Protected Interoperable File Format
PLC	Power Line Communications
QAM	Quadrature amplitude modulation
REPG	Reverse EPG
RGW	Residential Gateway
SCN	Service Class Names
SC-QAM	Single Carrier-QAM
SCR	Video Scrambler which integrated with a CA encrypts the video
SD	Standard Definition
SDH	Synchronous Digital Hierarchy
SDI	Serial Digital Interface
SF	Service Flows
SG	Service Group
SPTS	Single Program Transport Stream
STB	Set Top Box
SVOD	Subscription VoD
TS	Transport Stream
TV	Television
TVOD	Transactional VoD
UHD	Ultra-High Definition
UI	User Interface

URL	Uniform Resource Locator
USB	Universal Serial Bus
UTP	Unshielded Twisted Pair
UX	User experience
VBR	Variable Bit Rate
VoD	Video on Demand
WebVTT	Web Video Text Tracks Format
WiFi	Wireless Fidelity

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