# Guaranteeing Seamless 4K OTT Content Delivery

A Technical Paper prepared for SCTE•ISBE by

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# Introduction

Today OTT is becoming a common way of delivering video to the home, with Wi-Fi as the transport medium once inside. Wi-Fi quality of experience (QoE) is far from acceptable in today's deployments, and streaming solutions try to overcome this disadvantage by using adaptive streaming algorithms and packet prioritization techniques. However, when a consumer chooses to stream 4k content from an OTT service, he or she will not be satisfied with SD video quality due to bad Wi-Fi.

Today's full home coverage solutions offer a combination of RRM/SON capabilities, extenders and roaming solutions. Although these solutions vastly increase the Wi-Fi QoE for the subscriber, they are unable to guarantee a 4k video service delivery over Wi-Fi.

Technicolor is convinced the desired experience for a subscriber lies in a dynamic, self-adapting home network. Dynamic is the key word, as it ensures the Wi-Fi network does not impact non-video applications when there is no video content active. All services need to blend seamlessly, without creating an impression that a consumer needs to sacrifice. Furthermore, the network needs to be able to deal with environmental changes, without noticeable impact for the subscriber.

A dynamic, service-aware system that can monitor and guarantee 4k OTT content delivery must be capable of the following:

1) Detection: Dynamic identification of video service flows and required bandwidth.
2) Monitoring: Through continuous monitoring of the system, indicate whether video service quality was adequate at any moment in time.
3) Proactive care: The system will proactively steer non-video devices to other bands or access points, to reduce their airtime consumption and safeguard the 4k video services.
4) Reactive care: In cases where Wi-Fi issues are so impactful that 4k video quality cannot be guaranteed, the system must indicate root causes and potential cures for the future.

# Guaranteeing Seamless 4K OTT Content Delivery

## 1. A Burning Platform

Over-the-top (OTT) video streaming is quickly becoming a common way of delivering video to the home, with as many as 13% of US citizens having fully abandoned traditional cable and satellite TV services today (see Figure 1) and with many more using one or more OTT video streaming services alongside traditional TV. The adoption of ultra-high definition (UHD) quality content is also moving faster for OTT compared to traditional TV. All in all, OTT video is both a significant and a demanding internet service.

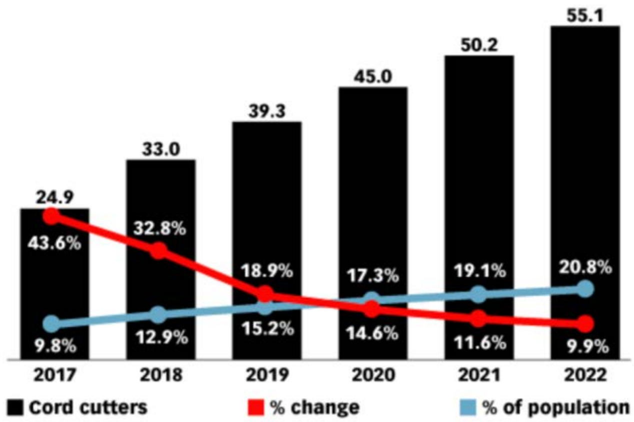


**Figure 1 - Evolution of cord cutting in USA[1]**

Streaming video service providers obviously want their subscribers to enjoy an optimal quality of experience (QoE). In achieving this they are at the mercy of the quality of their subscribers' broadband and in-home network connections. Video streaming solutions try to overcome poor network performance issues by applying adaptive streaming algorithms[2] and packet prioritization techniques. However, when a consumer pays a premium in order to stream UHD content, he or she will not be satisfied with standard definition (SD) video quality due to bad broadband or bad Wi-Fi.

Consumers easily recognize video quality issues related to network performance. Consumers expect their internet service provider (ISP) to provide the required bandwidth (CAPEX investment) and technical support (OPEX cost) and will, almost instinctively, raise any issues first with the ISP before addressing their streaming video service provider, if ever. QoE issues have a negative impact on an ISP's net promoter score (NPS) and therefore the ISP wants to assure that their network services meet the requirements for an optimal OTT video QoE.

More and more network connections are wireless connections and we know that in-home Wi-Fi is already a pain point today. Combine that with the increased bandwidth requirements of UHD content and we see a big risk for ISPs who fail to guarantee seamless UHD content delivery in the home. On the flip side, ISPs who do succeed in this will surely benefit.

In this paper we explain how to achieve this with a solution based exclusively on Wi-Fi metrics. In other words, we will not rely on application level metrics, because these are often unavailable to ISPs.

## 2. Market Overview

In this chapter we look at the penetration rate of OTT video in terms of media players and the availability of UHD screens and content. We then look at the use of Wi-Fi connectivity by OTT media players.

### 2.1. Streaming Video Players

Providers of streaming video services rely on video client hardware and/or software to get their content in front of the consumer. The most widely available clients are websites and apps running on desktop PCs,

[1] eMarketer, July 2018; cord cutters are defined as individuals (millions) of age 18+ who no longer have access to traditional pay TV services
[2] Deepthi Nandakumar, Sagar Kotecha, Kavitha Sampath, Pradeep Ramachandran, Tom Vaughan. "Efficient Multi-Bitrate HEVC Encoding for Adaptive Streaming". IBC, 2016

 

laptops and smartphones. As such, almost every consumer with a broadband connection can access streaming video services. For an optimal viewing experience, however, the preferred video clients are ISP managed set-top-boxes (STB), over-the-top (OTT) media players, games consoles and smart TVs because these allow media to be consumed on large screens in the comfortable space of the living room.

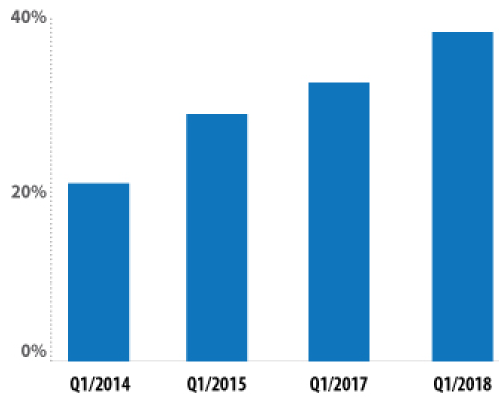


**Figure 2 - Ownership of streaming video players in USA[3]**

OTT media players are penetrating consumer households at a steady rate. According to research from Parks Associates, ownership of media players has risen from about 6% of U.S. broadband households in 2010 to almost 40% at the beginning of 2018 (see Figure 2). Four vendors Roku (Roku TV), Amazon (Fire TV), Google (Chromecast) and Apple (Apple TV) together hold about 90% of this market. ComScore paints a similar picture of the streaming video services and their OTT media players adopted by US households (see Figure 3).

Besides dedicated video client hardware, streaming video services can also rely on video client software, usually in the form of apps, deployed to set-top-boxes and smart TVs. The same research from Parks Associates teaches us that more than half of U.S. broadband households own a smart TV and, of those households, almost half own an OTT media player in addition to the smart TV.

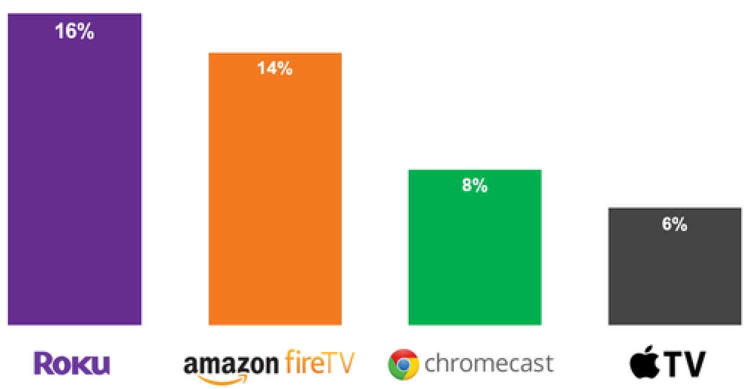


**Figure 3 - Penetration of OTT media players in US households[4]**

[3] Parks Associates, May 2018
[4] comScore, April 2017

 

### 2.2. UHD Screens and Content

The success of the UHD market is determined by the availability of UHD screens and the availability of UHD content. According to Parks Associates, UHD purchases represented 30% of US flat-panel screen purchases in 2017. According to information from Statista, a similar percentage of almost 30% is predicted for total TV shipments worldwide (see Figure 4).

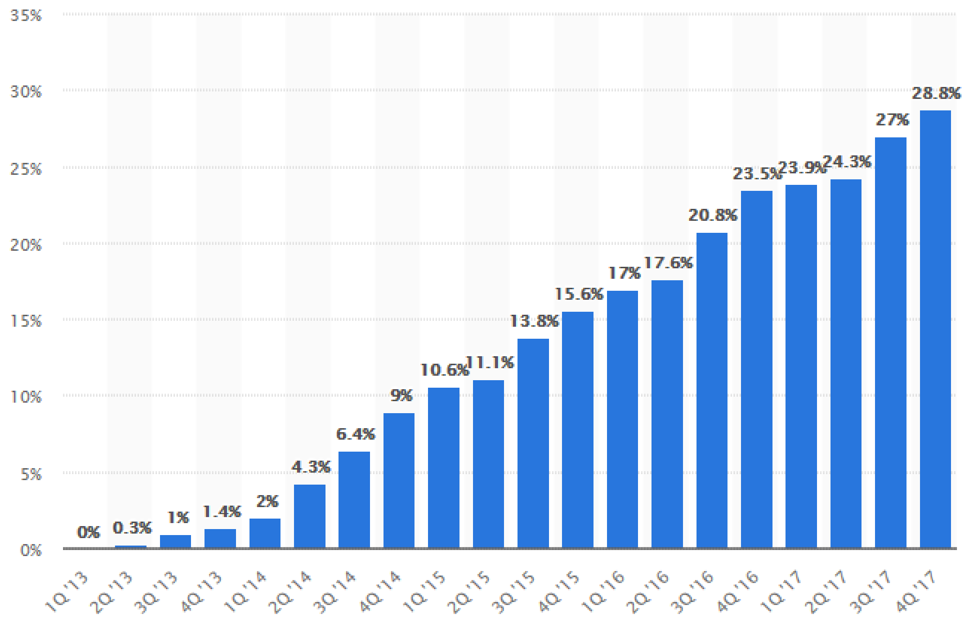


**Figure 4 - UHD TV shipments as percentage of total TV shipments worldwide[5]**

Futuresource Consulting, who forecasts 35% of global TV sales in 2017 will be UHD, puts the worldwide household penetration of UHD TVs to 8%.[6]

There is a gap in the availability of screens versus the availability of content and the ability to deliver it. While more and more new video content is being produced in UHD, the majority share of existing content in content libraries is older content produced in lower quality formats. Both Futuresource Consulting and The Guardian see ISP own broadcast services—which still represents the primary video delivery method available to most consumers—lag behind in UHD content delivery versus streaming video services.[7]

### 2.3. UHD Video Streams

ITU-T approved the initial release of the H.265 video codec standard, enabling image resolution of up to 8192 by 4320 pixels, on April 13, 2013. Without any compression, transport of images at the maximum resolution would require a bitrate close to 50 Gbps.

Thanks to work in ITU-T and the MPEG forum, a next-generation compression technique has been defined with a higher efficiency than its predecessor (H.264). The new codec enables UHD video streams

[5] Statista, December 2014
[6] Futuresource Consulting, “4K UHD Content is Now Abundantly Available, but it's Not Reaching Devices”, November 2017
[7] The Guardian, “2018 will be the year 4K TV goes big, but HDR still lags behind”, December 2017

 

to be delivered over widely available broadband and home connectivity solutions at speeds of a few tens of megabits. This is the H.265 video codec (also known as HEVC or the VP9N alternative), the successor to the H.264 codec (also known as MPEG 40 AVC). Specifically designed for optimal performance at ultra-high resolutions and high frame rates, it enables even higher accuracy for displaying motion images (e.g. sports, large screen movies).

ITU-T H.265 defines resolutions up to 8k. However, the industry is commonly adopting the 4k video format first.

ITU-T H.265 defines the 5.1 "main tier" video codec up to 40 Mbps[8] which means that a product supporting this profile must be able to digest the 40 Mbps video transport stream, at a resolution of 4096x2160. It can be argued that the real target rate will be lower because the UHD resolution which has been mainly adopted today for TV is not based on the highest resolution.

Which actual bitrate will be used finally is unpredictable. Given the vast number of possible permutations (frame rate, chromatic subsampling, resolution, etc.) a long list of options will be available. The goal of this paper is not to predict the rate, but to define requirements for a Wi-Fi system that can handle the required throughput, which is why worst-case bitrates are used to assess the impact and define the solution architecture.

## 2.4. Wi-Fi for Multimedia Access

Although the 802.11 wireless local area network (WLAN) specification was not designed to transport video, its widespread popularity as a LAN interface has led many suppliers to seek to provide multimedia access via Wi-Fi. They have encountered numerous challenges. The more the WLAN standard has evolved, the more features have been added to help attain the multimedia distribution target.

With the release of 802.11a/g, Wi-Fi technology was able to transport non-real-time audio (e.g. MP3, WAV, FLAC streaming) reasonably well. However, IPTV streaming remained challenging due to an absence of multicast support and insufficient PHY layer techniques to support stable high bandwidths.

As 802.11n was adopted, some companies, including Technicolor, started to look at Wi-Fi products capable of transporting high-end IPTV applications. This was achieved through proprietary techniques (e.g. HW acceleration for Ethernet frames in an embedded SoC) and optional items in the 802.11n standard (e.g. explicit transmit beam-forming, LDPC, etc.).

In addition to IPTV distribution, many local content distribution systems were developed using either core or optional parts of the 802.11n standard. These systems benefitted greatly from the higher PHY rates and improved RF stability introduced with MIMO. The biggest drawback of all these systems remained broad scale interoperability. This was to be expected: many optional/proprietary features were enabled on top of the limited set of 802.11n core features for which the Wi-Fi Alliance provided an interoperability certification test plan.

The introduction of 802.11ac in 2013 and the accompanying 802.11ac certified certificate by the Wi-Fi Alliance addressed these issues. Not only did 802.11ac drastically improve interoperability, it also introduced new features. Thanks to the introduction of QAM 256 and 80 MHz/160 MHz modulation, the standard enables large bandwidth boosts and forward error correction. This created rich new opportunities for multimedia distribution over Wi-Fi.

[8] ITU-T H.265 Annex A.4/Table A.1

 

Today, more and more network connections are wireless connections, be it Wi-Fi, mobile or other wireless technologies like Bluetooth. According to Cisco research, wireless devices accounted for 60% of all Internet traffic in 2015 and this share will rise to 78% by 2020 (see Figure 5). This trend is of particular concern to customer experience, knowing that getting connected through Wi-Fi is a major pain point today. Technicolor's own research shows that 1 out of 2 consumers experience Wi-Fi issues at home. This finding is corroborated by ISPs who systematically rank Wi-Fi-related issues (configuration, coverage, compatibility) at the top of their list of customer support tickets.

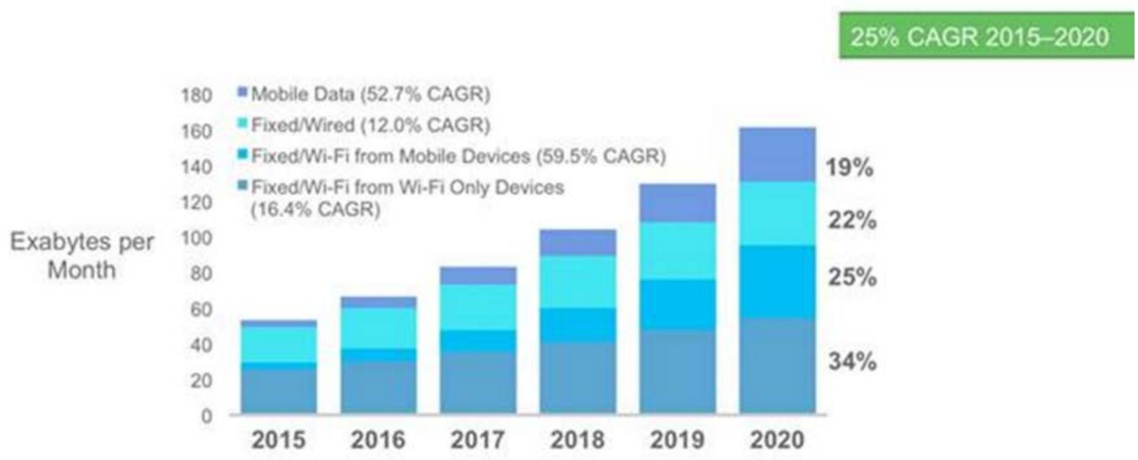


**Figure 5 - Growth of Internet traffic, fixed and wireless[9]**

## 3. Wi-Fi Performance Requirements For A Seamless UHD Experience

Robust streaming of UHD quality video content requires a sufficiently fast and stable network connection all the way from the video distribution platform (in the network) to the video client (in the home). In this paper we focus on LAN performance and in particular on Wi-Fi performance, which is often the weakest link, and we assume that WAN performance is sufficient.

Before proceeding with requirements, we first describe how to quantify and how to qualify Wi-Fi performance.

### 3.1. Quantifying and Qualifying Wi-Fi Performance and Performance Losses

In the next paragraphs we will show several figures which represent the performance of a Wi-Fi link between a Wi-Fi access point (AP) and a Wi-Fi station (STA). In these figures, the actual performance of the Wi-Fi link is plotted vs. its maximum theoretical performance. The maximum theoretical performance, or the maximum PHY rate, is determined by the Wi-Fi link configuration which includes the chosen Wi-Fi technology (e.g. 802.11n or 802.11ac), frequency band (e.g. 2.4GHz or 5GHz), bandwidth (e.g. 20MHz, 40MHz or 80MHz), MIMO configuration (e.g. 1x1, 2x2, 3x3 or 4x4) and short guard interval (SGI). The Y-axis of the figures represents the maximum PHY rate. The X-axis represents time.

In practice, the maximum theoretical performance of a Wi-Fi link is never reached due to a combination of factors. These factors can be qualified into three categories of issues:

[9] Cisco Visual Networking Index Global IP Traffic Forecast, 2015

 

1. **Physics issues** arise from poor Wi-Fi coverage (STA too far away from the AP) stemming from long range and/or from constructions which heavily degrade the Wi-Fi signal (reinforced concrete walls, insulation, metal doors …). Physics issues are what most people think of first when it comes to Wi-Fi issues. Whenever Wi-Fi link issues are experienced, end users instinctively check the "connection bars" on their device which indicate the signal strength of the Wi-Fi connection. Received signal strength (RSSI), a derivative of signal to noise ratio (SNR), relates directly to the maximum throughput[10] or link capacity that can be achieved over a link. The further a STA is moved from an AP, the lower the achievable link capacity gets.
2. **Interference issues** arise from a destructive use of the shared Wi-Fi medium. Interference can be caused by a non-Wi-Fi RF interferer transmitting in a Wi-Fi frequency band or by two faraway Wi-Fi access points (so-called hidden nodes) generating collisions at the location of a Wi-Fi station because the access points are too far away to coexist and share the medium in a proper way. Interference issues are often underestimated due to the complexity of detecting and diagnosing them as opposed to physics issues. Distinguishing between interference seen on the side of the AP (near-end interference) and on the side of the STA (far-end interference) is important when determining the root cause.
3. **Saturation issues** arise from overutilization of the shared medium by other stations belonging to the same network. This can stem from one station that completely saturates the available Wi-Fi medium with P2P downloads or from the sum of many stations.

In the figures, we use a color scheme to quantify how much of the maximum theoretical performance is lost due to each of these factors:

1. Blue: physics issues
2. Red and orange: far-end and near-end interference issues
3. Yellow: saturation issues

The actual performance of the Wi-Fi link is shown in two shades of green, where dark green represents traffic to/from the station and light green is the available (unused) link capacity.

Figure 6 is an example of such a Wi-Fi link performance graph.

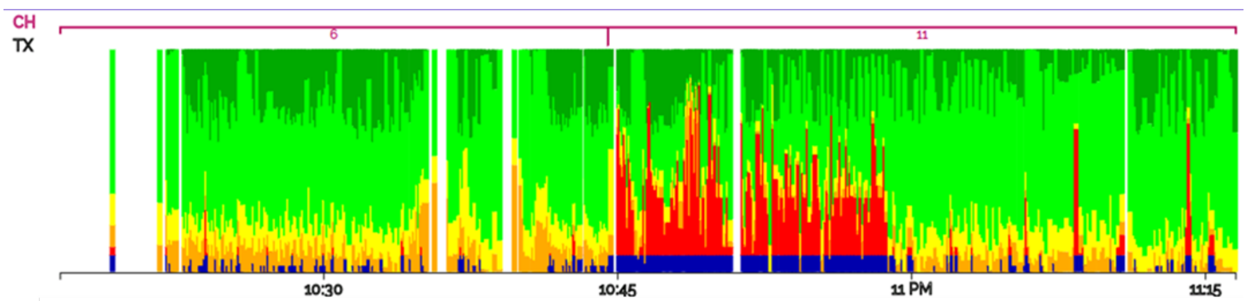


**Figure 6 - Example Wi-Fi link performance graph[11]**

[10] SNR defines the physical layer or modulation rate which is related to the actual throughput experienced by an end user. The relation between both can be expressed by a simple approximation of [throughput = PHY rate x MAC efficiency], whereby the MAC efficiency factor is a representation (in %) of the throughput loss due to framing overhead between the physical layer and the MAC layer. As such, it should be clear that the throughput degrades when the physical layer rate degrades.

[11] Technicolor, 2017

 

### 3.2. Throughput

When talking about performance, throughput is the most commonly used metric. In the following table, we compare the network throughput requirements for different qualities of video content as specified by three popular video streaming providers: Netflix, Amazon's Prime Video and Google's YouTube. Netflix and Prime Video refer to "Internet speed requirements" while YouTube refers to "video bitrates". We will demonstrate later that neither definition fits the bill entirely.

**Table 1 - Network throughput requirements (in Mbps) by video quality**

| Quality | Netflix[12] | Prime Video[13] | YouTube (SDR)[14] |
|---|---|---|---|
| SD (1k) | 3 | Not specified | 5-7.5 |
| HD (2k) | 5 | Not specified | 8-12 |
| UHD (4k) | 25 | 15 | 35-68 |

Prime Video does not specify Internet speed requirements for SD and HD quality content. We assume this is because Amazon considers that the vast majority of Internet subscriptions can support these bitrates.

Prime Video and YouTube distinguish between SDR and HDR content in their requirements. While Prime Video specifies the same Internet speed requirements for SDR and HDR content alike—which we assume is either a simplification or a mistake—YouTube sets the requirements for HDR roughly 25% above those for SDR content.

Table 1 shows that the network throughput requirements for streaming UHD quality video are 4 to 5 times higher than those for HD quality video. This may come as a surprise to some consumers because UHD could be considered as "one" step up from HD and 4k could be considered as "twice" 2k. In reality, the resolution of UHD is 3840x2160=8.3M pixels compared to 1920x1080=2.1M pixels for HD, hence the factor 4 to 5 increase of bitrate for UHD vs. HD.

Going from SDR to HDR does not increase the number of pixels but rather increases the color depth from 8 to 10 bits per pixel, hence the 25% increase of bitrate for HDR vs. SDR.

As video encoding technology advances, we may expect a reduction of network throughput requirements for a given video content quality. The uptake of such optimizations is slowed by interoperability concerns. Video streaming providers are incentivized to use more commonly supported video codecs so that they can reach wider audiences with video clients based on older hardware and software platforms. Therefore, we expect these network throughput requirements to remain stable in the next years. As an example, the encoding profiles used by Netflix[15] include both older and newer technologies: VC1, H.264/AVC Baseline, H.264/AVC Main and HEVC.

When the base network throughput requirement for streaming UHD quality video content is not met, then the adaptive streaming algorithm will automatically scale down to lower qualities. Figure 7 shows a real-life example of this scenario. An OTT device (LG 4k TV) is connected to the Internet via a poor Wi-Fi link. Even though the specific Wi-Fi configuration used here could yield a maximum theoretical

[12] "Internet Connection Speed Recommendations", https://help.netflix.com/en/node/306, June 2018
[13] "Prime Video Quality & Formats", https://www.amazon.com/gp/help/customer/display.html?nodeId=201648150, June 2018
[14] "Recommended upload encoding settings", https://support.google.com/youtube/answer/1722171, June 2018
[15] "High Quality Video Encoding at Scale", https://medium.com/netflix-techblog/high-quality-video-encoding-at-scale-d159db052746, December 2015

throughput of 144Mbps (11n, 2x2 MIMO, 2.4GHz band, 20MHz bandwidth), poor coverage (the blue in the figure) and to a lesser extent far end interference (the red in the figure) are restricting the actual throughput on this Wi-Fi link to roughly 15Mbps. When playing UHD content (Netflix, The Crown, season 2, episode 5) on this link, the adaptive stream never scales beyond HD quality.

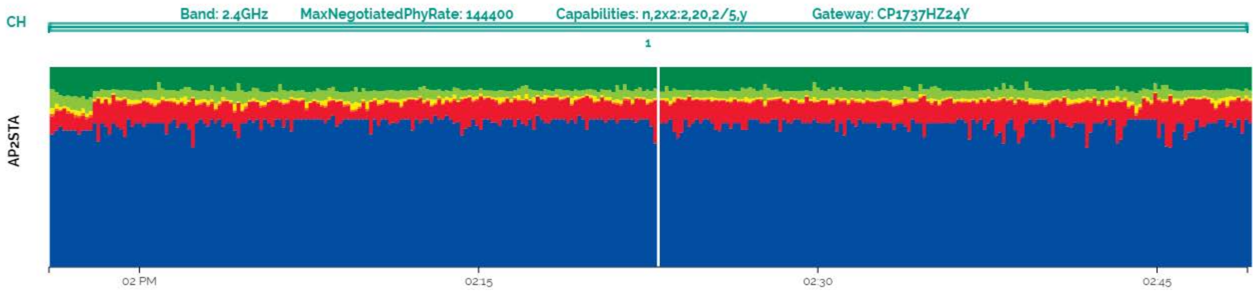


**Figure 7 - Poor Wi-Fi connection prevents upscaling to UHD**[16]

In this example we obviously cannot speak of a seamless UHD experience. The consumer who has invested in a 4k TV, a faster broadband connection and/or a UHD video streaming plan (some providers like Netflix charge extra for access to UHD quality content) will be unhappy. Sustained unhappiness will affect the profitability of Internet service providers and video streaming providers alike. The ISP will see OPEX increase as subscribers call for customer service. Both the ISP and the video streaming provider will see ARPU decrease as subscribers give up on premium broadband and video plans and will see increasing rates of churn.

Figure 7 is a good example of why the definition of “Internet speed requirements” maintained by Netflix and Prime Video misses the mark. The broadband connection is shared by multiple devices and applications in the home. When using Wi-Fi to connect the video client, a variety of factors can lead to an actual speed which is well below the Internet speed. A much better definition would be “speed requirements for the connection to your video client”.

### 3.3. Sustained Throughput Vs. Peak Throughput

In their Internet speed requirements, video streaming platforms neglect to mention the impact of peak throughput on the UHD experience. Why is peak throughput important? Video streaming clients always strive to maintain a buffer of several seconds of content in order to compensate for temporary drops in network throughput or even temporary loss of the network connection. When launching a new video, the client will hold off before playback until its buffer has been filled above a certain threshold. The duration of this delay depends on the peak network throughput: with a higher throughput the buffer will be filled faster, and vice versa. With a higher peak throughput, playback will commence sooner, which improves the UHD experience. This effect is not only noticeable when commencing a video, but also when skipping through a video forward and backward.

Figure 8 shows an example of buffering under ideal conditions. Our OTT device (LG 4k TV) is now connected to the Internet via an excellent Wi-Fi link. The specific Wi-Fi configuration used here yields a maximum theoretical throughput of 867Mbps (11ac, 2x2 MIMO, 5GHz band, 80MHz bandwidth). Some performance losses due to coverage (the blue in the figure) result in an actual throughput on this Wi-Fi link of roughly 650Mbps, which is far beyond the requirements of UHD video. When playing UHD

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[16] Technicolor, June 2018

 

content (Netflix, The Crown, season 2, episode 1) on this link, video playback commences promptly and immediately in UHD quality.

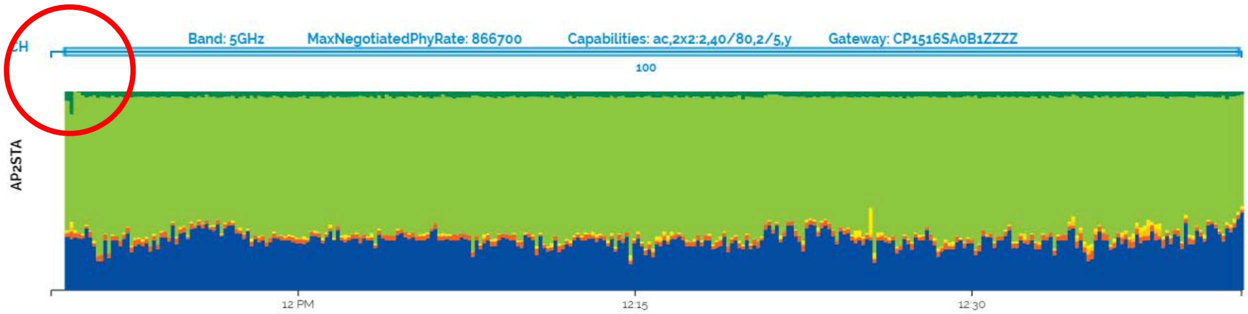


**Figure 8 - Buffering at start of new video playback (excellent conditions)**[17]

In this example, the data rate at the time of buffering climbs above 100Mbps before converging to a steady rate of 20Mbps.

Figure 9 shows another example of buffering under seemingly ideal conditions. Our OTT device (LG 4k TV) is connected to the Internet via a good Wi-Fi link. The specific Wi-Fi configuration used here yields a maximum theoretical throughput of 144Mbps (11n, 2x2 MIMO, 2.4GHz band, 20MHz bandwidth). Some occasional coverage issues (the blue in the figure) result in an actual throughput on this Wi-Fi link varying between 100Mbps and 120Mbps, which is still well beyond the requirements of UHD video. However, when playing UHD content (Netflix, The Crown, season 2, episode 2) on this link, it takes a few seconds longer to commence video playback compared to the previous example. What's more, initially the video codec commences in HD quality before scaling up to UHD quality (and staying there for the duration of the video).

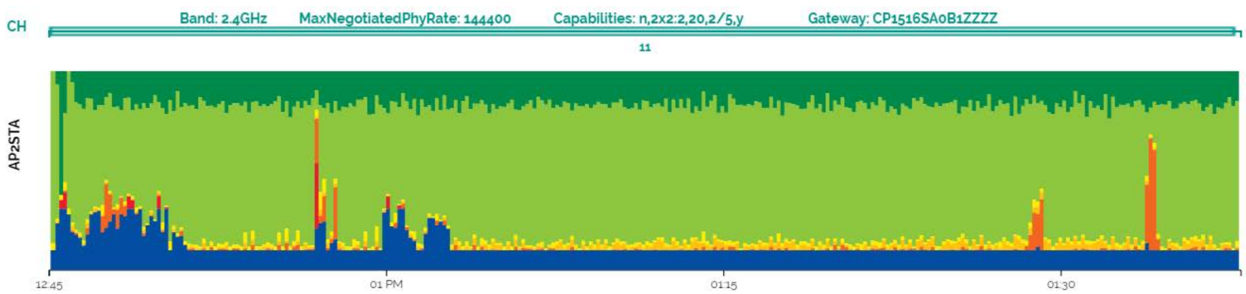


**Figure 9 - Buffering at start of new video playback (good conditions)**[18]

In this example, the data rate at the time of buffering climbs to about 60Mbps before converging to a steady rate of 20Mbps.

What we learn from these two examples is that, in order to guarantee a truly seamless UHD experience, network throughput requirements should be set higher than what the video streaming platforms specify.

### 3.4. Duration of Temporary Bandwidth Constraints

Just like adaptive streaming algorithms will scale down to lower qualities when placed under bandwidth constraints, you would expect them to scale back up once the bandwidth constraints have been lifted. This

[17] Technicolor, June 2018
[18] Technicolor, June 2018

 

is indeed the case after short periods of constrained bandwidth, but when the bandwidth is constrained for a longer period of time then an adaptive streaming algorithm may "give up" and never scale back up to the best quality. Figure 10 shows an example of this scenario. Our OTT device (LG 4k TV) is still connected to the Internet via a poor Wi-Fi link with the same configuration as in Figure 7. The difference is that for the first 45 minutes a combination of poor coverage and far end interference leads to extreme bandwidth constraints, which causes the adaptive streaming algorithm to scale down to SD quality. Even when the interference is removed, the codec remains at SD quality until the end of the episode. Video quality scales up to HD quality only upon starting the next episode.


**Figure 10 - Codec recovery[19]**

What this example teaches us is that, while short periods of bandwidth constraints will be transparent to the consumer as long as the buffer is not depleted, longer periods will reduce the video experience. First of all, the codec will scale down to a lower quality level. If the bandwidth constraints last for too long, the codec will not scale back up even when the constraints are lifted.

# 4. Diagnosing Video Quality Of Experience Issues Based On Wi-Fi Metrics

## 4.1. Levels of Inference

The most accurate way to assess the end user quality of experience of streaming UHD quality video content over Wi-Fi is by asking the user for his or her opinion. User experience is subjective by nature and nothing trumps getting the user's opinion, which will be determined by everything from personal taste, prior experience and visual acuity to screen size, viewing distance and Wi-Fi performance. The goal we have set out in this paper, however, is to assess QoE in an automated fashion based on Wi-Fi quality metrics. Figure 11 shows some different levels of quality inference where user opinion and Wi-Fi metrics occupy opposite ends of the scale.

[19] Technicolor, June 2018

 

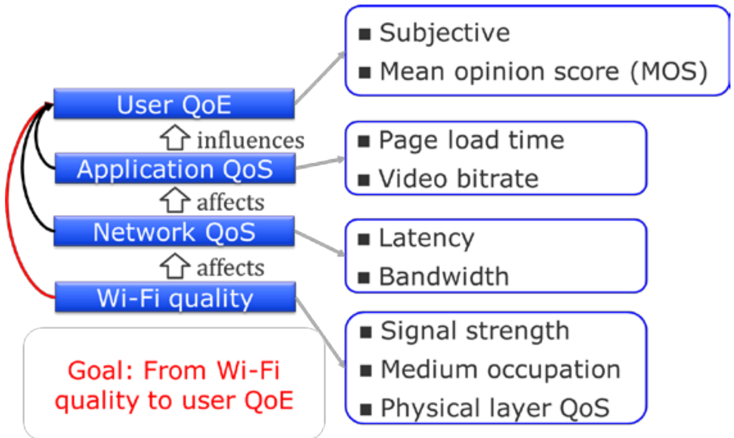


**Figure 11 - The effect of Wi-Fi quality on QoE[20]**

Why not focus on application metrics? Application-level diagnostics, in our application (i.e. video) running in the media player hardware and/or software, are well-placed to predict end user QoE. Video codec statistics such as the average frame rate, the resolution selected by the adaptive streaming algorithm and the buffer health (the number of video frames that have been buffered in order to overcome temporary connection issues) clearly indicate the robustness of the UHD video stream. Unfortunately, while these statistics are commonly available to the streaming video service, they are not commonly available to the broadband service provider, perhaps with the exception of joint offerings such as an integrated streaming video app on a set-top-box. So, in general, the broadband service provider needs a more accessible and independent basis for gauging the end user QoE than application metrics.

Network metrics, and Wi-Fi quality metrics in particular, can provide that basis. The ISP controls the broadband connection and monitoring broadband throughput, demonstrated earlier to be a key requirement for streaming video, yields useful data points to infer end user QoE. Broadband throughput is often inconclusive, however, because the broadband connection is just one part of the chain end-to-end and almost always an intermediate part (unless the media player is combined with the broadband access terminator) and often not the weakest part of the chain compared to the in-home Wi-Fi connection between the broadband access terminator and the OTT media player. It is therefore essential for the broadband service provider to monitor Wi-Fi performance in the home.

## 4.2. Detection of a Wi-Fi Video Client Device

A challenge in monitoring and optimizing the Wi-Fi performance of an OTT media player lies in identifying the Wi-Fi station which represents the media player. An OTT hardware device is, by nature, not provisioned by the service provider and therefore may resemble any other user device in the LAN. OTT traffic is also, by nature, not marked or classified in any particular way, unlike ISP managed traffic such as broadcast video or VoIP. When the OTT video client comes in the form of an app running on a multi-purpose hardware device, such as a tablet or a games console, it becomes even more difficult to recognize.

Several techniques of varying efficiency and effectiveness are available for identifying an OTT media player device and/or an OTT video stream:

[20] Diego Da Hora, Karel Van Doorselaer, Koen Van Oost, Renata Teixeira. "Predicting the effect of home Wi-Fi quality on QoE". IEEE International Conference on Computer Communications, April 2018.

- Deep packet inspection (DPI): A technique which identifies network devices and streams by inspecting network packets that are forwarded through a network node (e.g. the broadband router) and matching their payload against a database of fingerprints. OTT video devices can be identified by, for example, inspecting the User-Agent header in HTTP requests which often contains operating system and browser identifiers which can be mapped to specific devices like a Chromecast. OTT video streams can be identified by, for example, inspecting the public certificate used to secure the connection between client and server which can be mapped to specific services like Netflix. DPI is very effective but comes with steep hardware and software requirements which make it costlier to deploy than other techniques.
- Traffic pattern analysis: By analyzing the network traffic pattern of a device, the type of device or the type of service used by the device can be deduced. This technique requires access to sufficiently rich live or historical data and may not work well for devices which are used for more than one type of service such as a PC.
- DHCP options: When a network device requests an IP address using DHCP, it can include so-called DHCP options in its DHCP request to pass specific requests and extra information to the DHCP server. One of these options is the Vendor Class which is used to convey information about the vendor that manufactured the hardware on which the DHCP client is running. Typically, DHCP options can be used to identify an OTT device vendor such as Apple but not a specific OTT device type such as an Apple TV. On the flip side, because DHCP is so widely used, relying on DHCP options is cost-effective.
- MAC OUI: Every Wi-Fi station is uniquely identified at the data link layer by its MAC address. Part of this address (see Figure 12) is reserved for the so-called Organizationally Unique Identifier (OUI) which represents the vendor of the device as registered in the public and global OUI database managed by IEEE. As with DHCP options, MAC OUI can be used to identify a vendor but not a specific device type. MAC OUI is also cost-effective.

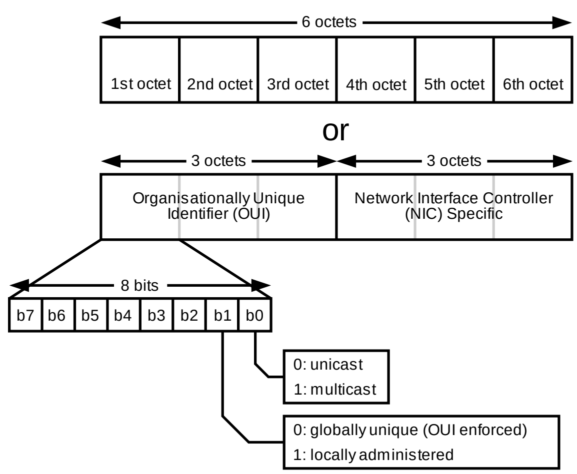


**Figure 12 - MAC address structure including OUI[21]**

- User-defined rules: An end user can manually identify or classify a device as being an OTT device using a web user interface or app provided by the service provider. This technique can be extremely accurate, but a drawback is that it requires interaction with the end user which can be perceived as an annoyance.

[21] Wikimedia, 2007

Regardless of which techniques are used to identify the OTT media player, the result is that we know which Wi-Fi station's performance to monitor.

## 4.3. Wi-Fi Performance Monitoring

Once we have identified the Wi-Fi station, we can monitor its Wi-Fi performance. From the practical experiments described in chapter 3, we distill three Wi-Fi performance metrics which must be monitored in order to assess OTT video QoE.

- Must be able to measure Wi-Fi link capacity, because this determines the generally obtainable video quality level and influences the video start and skip delay
- Must be able to measure available Wi-Fi link capacity for a given Wi-Fi station, not just for the Wi-Fi network as a whole, because the home network will be shared with other Wi-Fi devices
- Must be able to measure true Wi-Fi link capacity, because in reality the maximum PHY rate is never attained due to physics and far-end interference issues and the trained PHY rate is never attained due to near-end interference issues and normal sharing of the Wi-Fi medium
- Must be able to perform measurements at a high sample rate, because transient effects will cause QoE issues depending on video buffering settings

## 4.4. Diagnosis

As elaborated in chapter 3.1, Wi-Fi performance losses can be attributed to several factors like physics, interference and saturation issues. In order to recommend the appropriate course of action for mitigating performance losses, it is imperative to make the correct diagnosis first. Physics issues can be addressed by repositioning the Wi-Fi station or by installing additional Wi-Fi access points to improve coverage. Interference issues can be addressed by using a different channel within the same frequency band or by moving the Wi-Fi station to another band. Saturation issues can be addressed by increasing the Wi-Fi medium's overall capacity or by throttling other stations sharing the medium.

A Wi-Fi performance problem will often have more than one root cause and therefore more than one recommended course of action. Individual actions should be prioritized based on the contribution of every factor to the overall loss of performance. With the lessons learned from several large Wi-Fi deployments by Technicolor, we know that in 92% of the cases Wi-Fi performance losses are not linked to only one root cause. In 80% of the diagnosed cases there are two root causes.

 

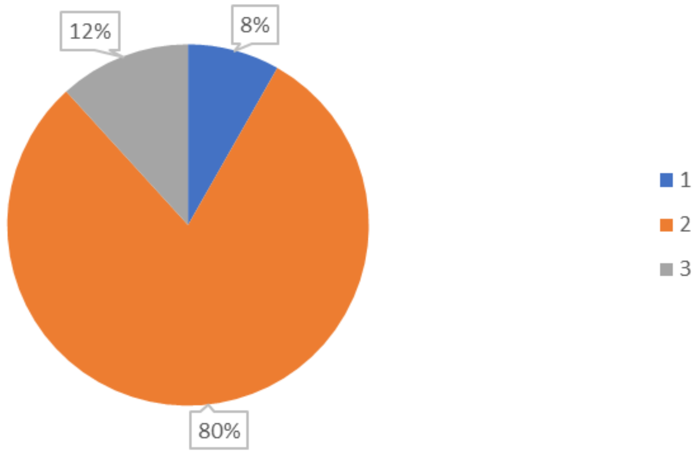


**Figure 13 - Distribution of number of root causes (out of physics, interference, saturation) affecting Wi-Fi performance losses[22]**

In the next chapter, we review various techniques to improve Wi-Fi experience in case of issues and we apply these techniques specifically to OTT video scenarios.

# 5. Service Assurance for Video Over Wi-Fi

Streaming video service providers want their subscribers to enjoy an optimal quality of experience. In achieving this they are at the mercy of the quality of their subscribers' broadband and in-home network connections, however. Consumers understand this too and recognize easily video quality issues related to network performance. They will, almost instinctively, raise these issues first with their internet service provider before addressing their streaming video service provider, if ever. OTT video quality of experience issues have a negative impact on an ISP's OPEX and NPS and therefore the ISP wants to assure their network services meet the requirements for an optimal streaming video quality of experience.

We can distinguish between proactive assurance and reactive assurance. Proactive assurance includes all measures for identifying and correcting or avoiding outright Wi-Fi performance losses before they manifest as QoE issues for the end user. This form of assurance is obviously preferred. Reactive assurance is when Wi-Fi performance issues are identified and corrected only after being reported by the end user.

## 5.1. Proactive Assurance

### *5.1.1. WMM*

The Wi-Fi Multimedia (WMM) standard defines basic Quality of Service (QoS) mechanisms for Wi-Fi traffic. By tagging certain traffic as voice or video, this traffic will be transmitted with priority versus traffic tagged as best effort and background. WMM is often used for IPTV distribution over Wi-Fi. Because IPTV streams are well-defined end-to-end from all the way from the access network to the STB, it is trivial to tag the traffic. A challenge for applying WMM to OTT video streams follows from chapter 4.2: in order to tag traffic, one needs to recognize it, and this is not obvious for an OTT media player device and/or an OTT video stream.

[22] Technicolor, July 2018

 

A drawback of WMM is that it is unfair to other Wi-Fi traffic: an OTT media player with weak Wi-Fi signal and low PHY rate receiving high priority traffic can starve all other traffic. By solving one issue for the end user, another is created. Therefore, WMM works best in Wi-Fi networks where there is enough airtime available to transmit all data within the home network.

#### *5.1.2. Airtime (un)fairness*

Airtime fairness is a feature that attempts to assign Wi-Fi airtime more fairly between Wi-Fi stations in the home network. The benefits of airtime fairness are most apparent when considering two different Wi-Fi stations, one slow and one fast. When transmitting an equal amount of data, without airtime fairness, the slow station would consume more Wi-Fi airtime (because it takes longer to transmit) than the fast station. An OTT media player that requires a lot of airtime to receive an UHD stream could experience starvation from other stations. With airtime fairness, the slow station will be throttled to give the fast station more airtime.

A drawback of airtime fairness is that being fair is not always best for the user experience. Being fair might cause an UHD quality video to scale down to HD quality while a large file is being downloaded to another PC, which is likely not what the end user wants. Some implementations of airtime fairness allow specific priorities to be set—making things a little more unfair on Wi-Fi level—in which case the challenge is again identifying the OTT media player.

#### *5.1.3. Band Steering*

WMM and airtime fairness are techniques that try to optimize the situation within a given Wi-Fi link capacity. Band steering is a feature that attempts to move dual-band capable Wi-Fi stations from the slower 2.4GHz frequency band to the faster 5GHz frequency band, thereby increasing the link capacity for the station. While a connection to 2.4GHz does not necessarily imply that the user experience is bad, it is well understood that a station capable of moving to 5GHz at a specific location will benefit from performing said action. The typical dual-band capable station employs an 802.11ac WLAN radio hence it can use 80MHz modulation rates on the 5GHz band whereas the 2.4GHz band generally only allows the use of 20MHz channels in 802.11n mode.

Many Wi-Fi stations will, under good conditions and when given an equal choice, prefer to connect to 5GHz already. However, we see that Wi-Fi stations will sometimes refrain from choosing 5GHz as preferred operational frequency band and can end up being stuck on 2.4GHz, potentially leading to a degraded user experience as the (maximum) link capacity is limited.

Certain conditions must be met before steering a Wi-Fi station to another band. First, we must confirm that the station is dual-band capable. If the OTT media player is not known beforehand, this capability can be derived from the 802.11 probe request[23] data. Second, we must confirm that the Wi-Fi station is able to connect to the access point on the other frequency band. This is achieved the most easily by assigning the same SSID and credentials to the 2.4GHz and to the 5GHz access point. If either of these conditions would not be met, then a band steering action would risk disconnecting the OTT media player from the network.

[23] Wi-Fi stations send 802.11 probe requests to known APs (and to broadcast MAC addresses) when they are (active) scanning the available channels. These probe request can be captured by an AP as they indicate the STAs ability to operate on a specific channel.

 

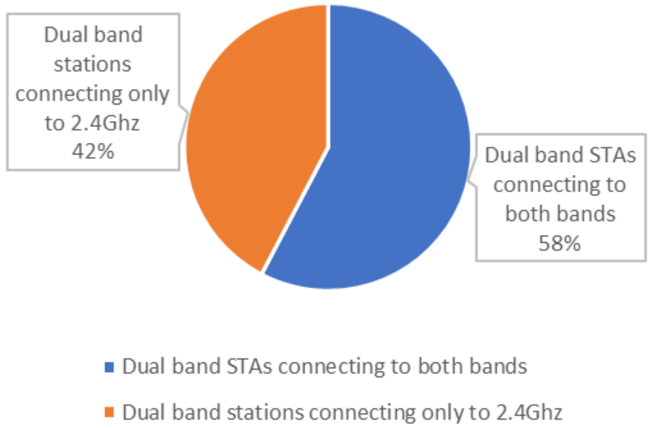


**Figure 14 - Percentage of dual-band capable Wi-Fi stations that do not connect to 5GHz[24]**

Figure 14 shows out of a large population of Wi-Fi households how many dual-band capable Wi-Fi stations actually connect to 5GHz. 42% of the stations does not connect to 5GHz even though they are capable of doing so. The reason for this is two-fold. On one hand, some of the households use a different SSID for each band and most consumers connect first to the 2.4GHz SSID and do not bother to configure the 5GHz SSID. On the other hand, even with the same SSID, certain Wi-Fi stations are "sticky" and refrain from connecting to 5GHz. This clearly demonstrates the need for unifying the Wi-Fi configuration in the home and for band steering.

### 5.1.4. Channel Planning

Channel planning[25] aims to select better Wi-Fi channels (within each frequency band, so on 2.4GHz and on 5GHz) to improve overall Wi-Fi link capacity within the constraints of the Wi-Fi environment (e.g. neighboring Wi-Fi networks).

The 2.4GHz frequency band is almost universally supported by Wi-Fi stations for historical reasons and is still widely used today. The band is divided in 13 channels (see Figure 15), of which only the first 11 are permitted in the United States. Only three of these channels are non-overlapping (1, 6, 11), meaning that in a dense Wi-Fi environment only three nearby access points can transmit without interfering with each other. Any additional access points trying to use 2.4GHz in the same location will cause interference. It is easy to understand why the 2.4GHz frequency band is so congested and why channel planning is needed to make the most out of it.

[24] Technicolor, July 2018
[25] Olivier Jeunen, Patrick Bosch, Michiel Van Herwegen, Karel van Doorselaer, Nick Godman, Steven Latré. "Data-driven Frequency Planning".

 

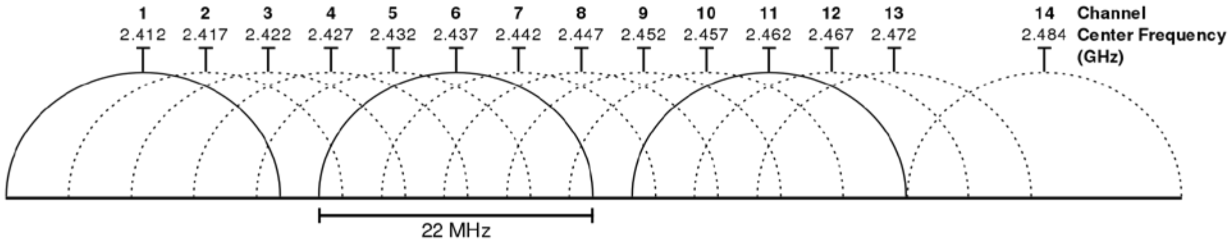


**Figure 15 - 2.4 GHz Wi-Fi channels[26]**

The 5GHz frequency band supports more than 20 non-overlapping channels when using a 20MHz bandwidth. Even with the bandwidth set to 80MHz there are still more choices available than in the 2.4GHz frequency band.

The impact of a channel change can be severe as we can see in the example of Figure 16. Until shortly before 7:00 PM a Wi-Fi station is suffering quite badly from interference (red and orange colors). This combined with the fact that the station is not very close to the access point (blue color) leaves almost no available link capacity remaining for user traffic. Just before 7:00 PM the access point is switched to channel 13 and the interference all but disappears.

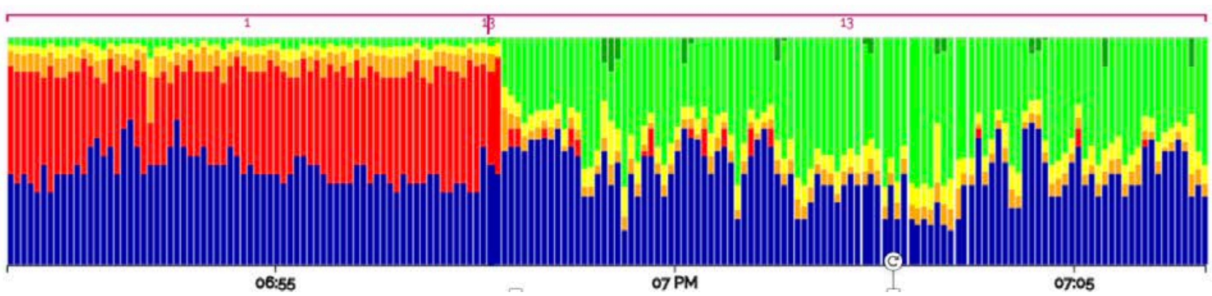


**Figure 16 - Interference patterns between channels 1 and 13[27]**

Most Wi-Fi access points employ a feature called Automatic Channel Selection (ACS) that periodically (e.g. several times a day) scans the regulatory allowed list of channels and reconfigures the access point to use the best channel seen at that moment. The periodic scan interval is not set very aggressive because the scans are service interrupting, except for access points with a dedicated scanning radio. This is a compromise knowing that Wi-Fi interference issues are often intermittent. A residential area will be largely empty during work hours and more vibrant during evenings and weekends, hence the Wi-Fi from those households will exhibit different patterns during the day. The same applies to office buildings but in the reverse. ACS will not catch on to these interference patterns because it only monitors periodically during very short intervals.

A limitation of most ACS implementations is that they are unable to recognize far-end interference. This implies that ACS would not have picked up the interference on channel 1 in the example of Figure 16. If the access point had remained on channel 1, obtaining a seamless UHD video experience would have been impossible. A good channel planning solution must be capable of distinguishing between near-end interference and far-end interference.

[26] Wikimedia, 2009
[27] Technicolor, 2017

 

The impact of channel planning on in-home Wi-Fi quality of experience is significant. Figure 17 shows aggregated results from five Wi-Fi deployments by Technicolor, of which three ISPs are using channel planning and two ISPs are not. Despite the mix of geographical regions and Wi-Fi access point products and configurations, it is easy to see who benefits from channel planning by looking at the percentage of households having an optimal Wi-Fi QoE: roughly 2 out of 3 households, compared to roughly 1 out of 2 households when no channel planning is used.

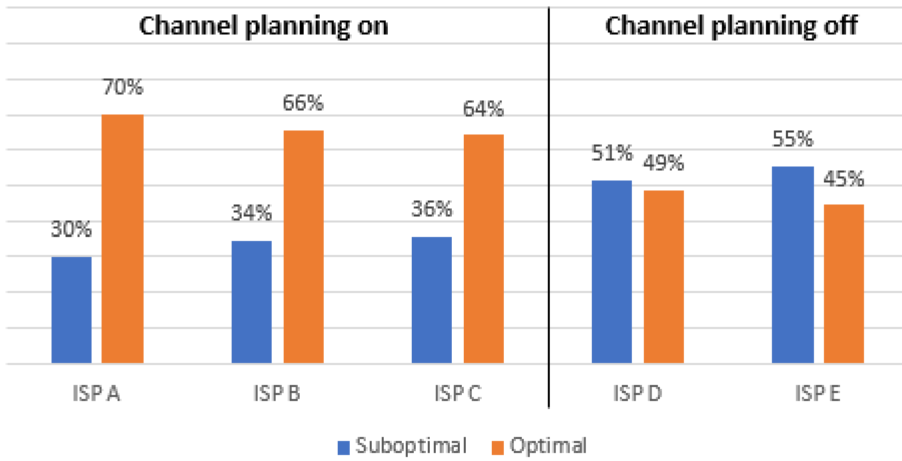


**Figure 17 - Households with optimal Wi-Fi QoE**[28]

Wi-Fi interference is location-dependent, which means that different channels will yield different performances for different stations throughout the home. A channel planning solution can be configured to give more weight to certain Wi-Fi stations such as an OTT media player.

To summarize, a good channel planning solution can complement traditional ACS implementations by recognizing far-end interference and by reacting to intermittent interference issues. Coincidentally, these considerations align well with the requirements for a Wi-Fi performance monitoring solution capable of assessing video QoE listed in chapter 4.3.

### *5.1.5. Client Steering*

It is becoming more and more common to extend Wi-Fi coverage in the home by deploying multiple Wi-Fi access points (a.k.a. Wi-Fi mesh networks). However, just having multiple access points does not guarantee that Wi-Fi stations will make the most efficient use of them. While the intelligence of roaming behavior, as initiated by the stations themselves, improves with every new generation of devices, the reality is that most devices in a consumer household are not updated nor upgraded very often. Next to that, a Wi-Fi station does not always have the means to assess the full environment and exploit it, when compared to the information that can be extracted by combining the view of several access points in the home. Last but not least, many Wi-Fi devices were simply not anticipated and designed to be nomadic. As a result, similar to the behavior seen with band steering, Wi-Fi stations can be "sticky" and refrain from connecting to the right access point in a multi-AP deployment. Client steering is a feature which addresses this challenge.

We identify several use cases within the realm of client steering in a multi-AP deployment:

[28] Technicolor, July 2018

 

1. **Signal strength-based roaming** is the most commonly supported use case where Wi-Fi stations that do not move autonomously are roamed proactively before the signal degrades to the point that QoE issues arise,
2. **Interference-based roaming** is a more advanced use case where Wi-Fi stations experiencing performance loss due to interference are roamed proactively to Wi-Fi access points on other channels or frequency bands,
3. **Load-based roaming** is a use case where Wi-Fi stations suffering from oversubscription of the Wi-Fi medium are roamed proactively in such a way that the overall load in the home Wi-Fi network is balanced.

The actual roaming action can be triggered in several ways. Per IEEE 802.11-2016, two mechanisms are defined. The most straightforward one is not really a roaming mechanism at heart, but rather a general-purpose disconnection mechanism that has existed ever since the first version of IEEE 802.11. This mechanism simply implies that an AP wishing to terminate an STA connection sends an IEEE 802.11 disassociation or a deauthentication frame to the target STA, typically combined with blocking future reassociation by applying an access control list. A second, more elegant roaming mechanism was introduced by adoption of the 802.11v substandard. In this case, a proper roaming request is sent from the AP to the target STA, allowing for a smoother transition. Ultimately, even when using 802.11v, every roaming action still carries a small risk of service interruption on application level and therefore roaming should be handled with care.

All of these roaming use cases apply to OTT video players. When the Wi-Fi performance requirements for a seamless UHD experience are not met, client steering can be applied to improve the link capacity and link stability. The fact that OTT video codecs use a generous buffer means that roaming should generally happen transparently for the end user. Nevertheless, a more failsafe approach exists which is to roam other Wi-Fi stations away from an access point in order to improve the Wi-Fi link for the OTT video player which stays behind. Also, it may be desirable to allow only the 802.11v roaming mechanisms for an OTT video player.

### 5.2. Reactive Assurance

When all proactive assurance measures fail, we must resort to reactive assurance, which implies that the end user is aware of the issue. It is still preferred to inform the end user proactively, rather than wait for the end user to call the helpdesk. This highlights the importance of having a Wi-Fi monitoring system which is capable of identifying or, better yet, predicting video QoE issues and alerting the ISP.

The most common scenario where the end user needs to be involved is when there is a Wi-Fi coverage issue. When a Wi-Fi station is truly too far away, some kind of manual action must be taken such as:

- Moving the station closer to an AP
- Installing an additional AP (a.k.a. a Wi-Fi extender)
- Moving an AP closer to the station (less practical when the main AP in the home is combined with the broadband access terminator)
- Upgrading an AP to a better performing AP
- Switching to a wired connection

The results of a case study into the incidence of radio path issues with different brands of OTT media players are shown in Figure 18. The Apple TV, Chromecast and Roku are found in significant quantities in Wi-Fi households using four different types of Wi-Fi access points. The Apple TV tends to exhibit less radio path issues than the Chromecast and the Roku, perhaps due to better Wi-Fi antenna design. More interestingly, the incidence of radio path issues is much smaller with AP C and AP D than with AP A and AP B. The explanation is that AP C and AP D have a better Wi-Fi antenna design, an increased MIMO and a higher Wi-Fi power output. This case study demonstrates that moving a Wi-Fi station or installing a Wi-Fi extender is not always required in order to fix a Wi-Fi coverage issue.

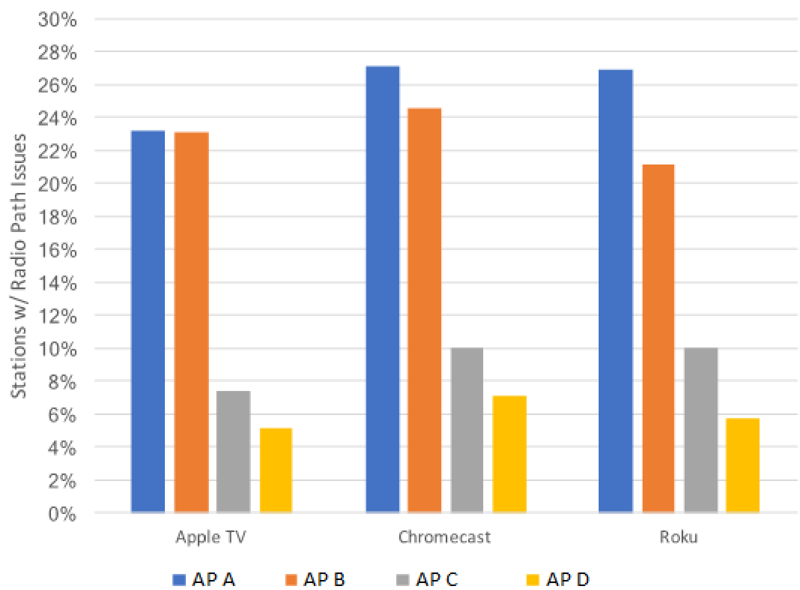


**Figure 18 - Incidence of radio path issues for OTT media players associated with four different models of Wi-Fi[29] AP**

# Conclusion

In this paper, we demonstrated that guaranteeing a seamless UHD OTT video streaming over Wi-Fi experience is achievable by deploying a dynamic, self-adapting home Wi-Fi network. The right solution relies on four key capabilities:

1. **Detection** of the OTT media player or OTT video stream,
2. **Monitoring** of the Wi-Fi link to the OTT device and of the whole home Wi-Fi network, in particular the accurate assessment of link capacity performed at a high sample rate and the accurate diagnosis of issues,
3. **Proactive assurance** to mitigate issues before they become apparent to the end user,
4. **Reactive assurance** to resolve those remaining issues that mandate end user involvement.

This enables ISPs to assure that their network services meet the requirements for an optimal OTT video QoE and elevate subscriber NPS.

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[29] Technicolor, 2017

 

# Abbreviations

| | |
|---|---|
| ACS | Automatic Channel Selection |
| AP | Access Point |
| CAPEX | Capital Expense |
| DHCP | Dynamic Host Configuration Protocol |
| DPI | Deep Packet Inspection |
| HD | High Definition |
| HDR | High Dynamic Range |
| HTTP | Hyper Text Transfer Protocol |
| IEEE | Institute of Electrical and Electronics Engineers |
| IPTV | Internet Protocol Television |
| ISP | Internet Service Provider |
| ITU | International Telecommunication Union |
| LAN | Local Area Network |
| MAC | Media Access Control |
| MDU | Multi-Dwelling Unit |
| MIMO | Multiple Input Multiple Output |
| MPEG | Moving Pictures Experts Group |
| NPS | Net Promoter Score |
| OPEX | Operational Expense |
| OTT | Over the Top |
| OUI | Organizationally Unique Identifier |
| P2P | Peer to Peer |
| PHY | Physical layer |
| QoE | Quality of Experience |
| QoS | Quality of Service |
| RF | Radio Frequency |
| RRM-SON | Radio Resource Management – Self Optimizing Networks |
| RSSI | Received Signal Strength Indication |
| SD | Standard Definition |
| SDR | Standard Dynamic Range |
| SGI | Short Guard Interval |
| SNR | Signal to Noise Ratio |
| SP | Service Provider |
| SSID | Service Set Identifier |
| STA | Station |
| STB | Set Top Box |
| UHD | Ultra-High Definition |
| WAN | Wide Area Network |
| WLAN | Wireless Local Area Network |
| WMM | Wi-Fi Multimedia |