



# DELIVERING TELEVISION-QUALITY VIDEO OVER WI-FI

## A Guide to Making the Right Wireless Equipment Decisions

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# INTRODUCTION

The combination of deep broadband penetration and mass adoption of connected devices with television quality displays is driving revolutionary change in home video consumption. TV watching, freed from the confines of the television set, is now taking place in every room in the house. And Wi-Fi is the technology that is delivering it.

Although consumers are increasingly watching on devices other than the television, they still expect TV quality. They aren't getting it. 34% report having problems streaming or downloading video at least 50% of the time.

Delivering IPTV television over Wi-Fi in the home is more difficult than OTT streaming video. Operators need to provide better wireless access points (APs) capable of delivering higher, more consistent bitrates over a larger area.

Home wireless services are delivered over two frequency ranges: 2.4GHz and 5GHz. The characteristics of the two bands differ, but wireless APs that leverage both typically deliver much better throughput than those that cannot.

Wireless AP device makers take two main approaches to ensure excellence in video delivery: maximizing the amount of bandwidth available and optimizing the way the available bandwidth is allocated.

Maximizing bandwidth is primarily achieved through hardware improvements:

- > More antennas - A 2x2 antenna AP delivered 26 Mbps at 16 Meters, while a 3x3 antenna AP delivered 57 Mbps from the same location.
- > Beamforming - More transmit energy is directed toward connected clients improving available bandwidth to them.
- > Use of an optimal wireless AP chipset - Some chipsets have power consumption or cost as primary concerns, while others optimize for coverage and performance.

Optimizing the way available bandwidth is allocated is achieved in two ways:

- > Bandwidth reservation - Techniques include using separate Wi-Fi frequencies for video and data, and reserving bandwidth for specific data types (such as video.)
- > Client management - Identify slow or marginal wireless clients and prevent them from impacting other clients, particularly those receiving video.

Many of these techniques are implemented directly in wireless chipsets that AP manufacturers use in their device designs. Though there is much variation in performance between chipsets, there are still marked differences in performance between different devices using the same chipset.

IPTV operators need to choose their wireless access point carefully. Delivering multicast IP video is more challenging than OTT streamed content. This requires a better quality, more flexible AP optimized for the delivery of IPTV video.

# THE NEW ENVIRONMENT FOR TELEVISION IN THE HOME

The combination of deep broadband penetration and mass adoption of connected devices is ushering in a revolution in video consumption in the home. In just one year penetration of smart TVs has more than doubled, from 16% to 35%. Mobile devices have also grown sharply with 43% now saying they have a tablet and 71% a smartphone.

## WHAT DEVICES DO YOU OWN?

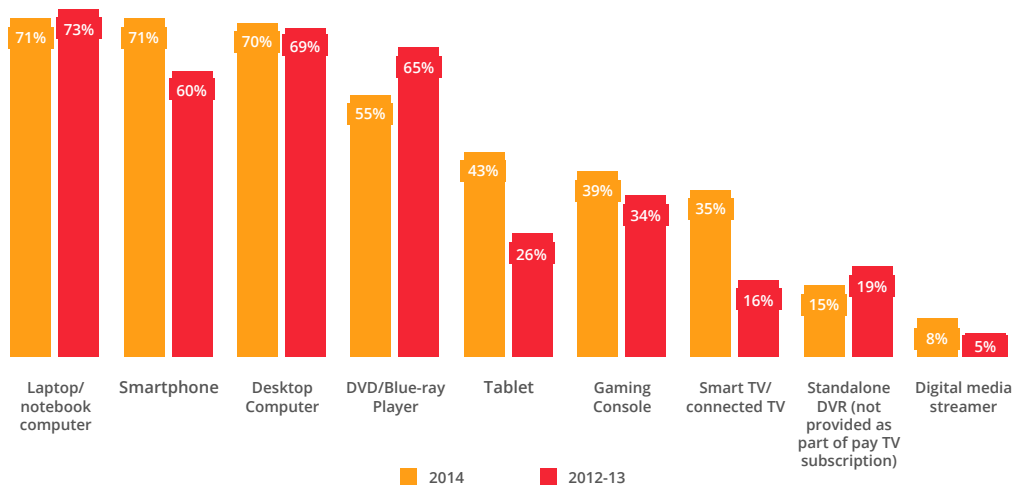


Figure 1: Mobile device penetration increases

All of these devices include great displays capable of delivering television quality experiences. Signs are pointing to consumers beginning to use them that way. For example online requests for TV programs from BBC iPlayer in the UK increased 61% between February 2012 and February 2014. For such premium content the tablet and smartphone are beginning to supplant the ubiquitous PC. In June 2013, 44% of BBC iPlayer Internet requests came from the PC. One year later request had fallen to 35%. Over the same period, tablet requests grew from 24% to 33% and smartphone requests from 21% to 23%.

Mobility is also having a remarkable effect on where people watch in the home. Of course, the living room remains the most popular location, with 61% watching paid TV there. The main bedroom, usually the location of a second TV, is also popular with 26%. With connected devices in hand, however, every room is a place where TV can be watched.

How does all this video get shipped around the home to the many connected devices? Wi-Fi is the foundation upon which all connected

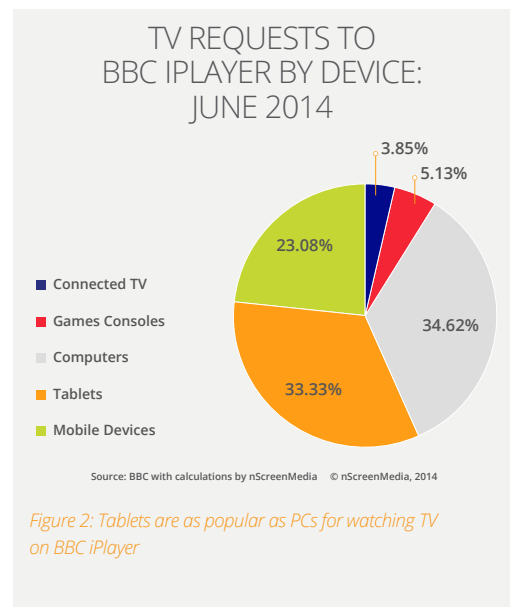


Figure 2: Tablets are as popular as PCs for watching TV on BBC iPlayer

services depend today. With 82% of consumers streaming video at least once a week, it is one of the most important data types depending on Wi-Fi to deliver a great experience. Unfortunately, video is the most taxing of all data to deliver in any environment, let alone one so fraught with challenges as the home wireless network.

Yet for many pay TV subscribers, that is precisely the environment they expect their operator to deliver in. And to do so with the same quality and reliability they have come to expect from TV.

## CONSUMERS EXPECT TV QUALITY

Over-the-top providers such as Netflix, NowTV, and Maxdome are doing a great job of delivering video services over the Internet. Using best efforts protocols like adaptive bit rate streaming have allowed these services to continue to provide video even when network conditions degrade. Unfortunately, in many cases that means video quality and viewing experience suffers.

When asked how often they encountered issues when streaming online video viewers reported problems in every country surveyed. On average, 34% of people said they had problems at least 50% of the time. Shockingly, 9% reported having problems every time they attempt to stream or download a video. The problem seems to be endemic across Europe. One quarter of people in Germany and the UK reported having problems every other time they attempt to watch an online video, while almost half of people in Turkey reported the same.

FREQUENCY OF ENCOUNTERING PROBLEMS WITH ONLINE VIDEO VIEWING

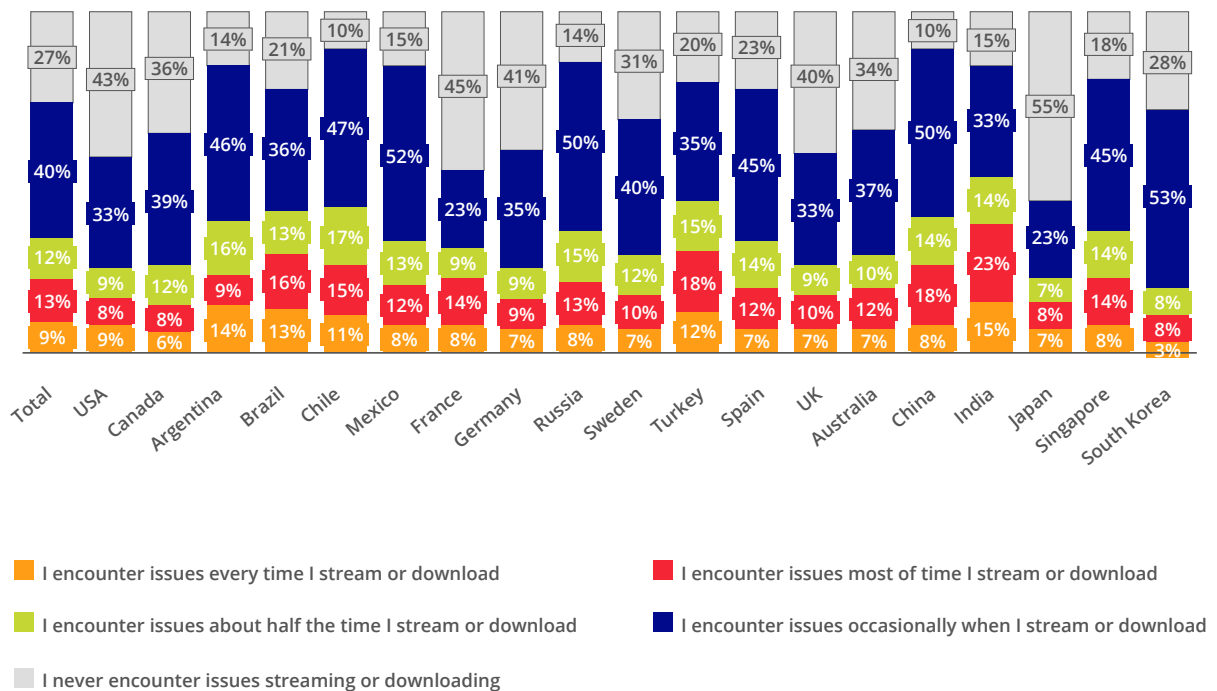
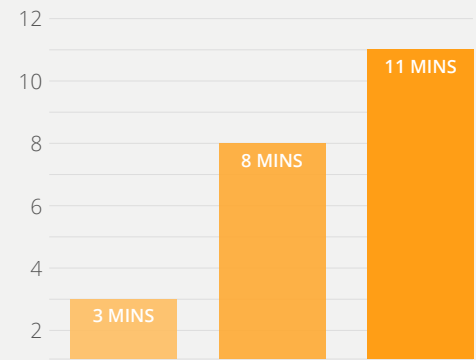


Figure 3: Frequency of encountering problems with online video viewing

The penalty for poor performance is very high, particularly if the video being watched stalls. Every OTT video viewer is familiar with the spinning pinwheel icon, while the device they are using waits for more video to arrive from the Internet. Tolerance for such events is growing thin. In 2011, a 1% increase in buffering events resulted in three minutes less video viewing. By 2013, that had grown to 11 minutes. Clearly, the online video viewer is increasingly expecting television-like performance from their online viewing experience.

For IPTV providers this situation is particularly challenging. Subscribers expect to be able to watch live, on-demand, and DVR television on all of their devices. Yet they expect nothing less than television quality. That means operators must take the carefully controlled IPTV service they deliver to the set-top box and transition it to a Wi-Fi network to reach all of the connected devices throughout the home.

### OTT VIEWER TOLERANCE FOR VIDEO PROBLEMS IS DECREASING



Source: ComViva, 2014

Figure 4: OTT viewer tolerance for video problems is decreasing

## DELIVERING IPTV QUALITY OVER WI-FI IS A CHALLENGE

There are some important differences between IPTV and OTT delivery that make performance of the wireless access point particularly important for IPTV services. IPTV uses much higher bit rates for the video than is typically used for OTT. While OTT services use adaptive bit rate streaming IPTV uses constant bitrate streams. Also, since OTT uses TCP protocols common to many Internet services, if there is an error in sending some of the video data the protocol automatically re-sends that data. IPTV solutions typically use a different protocol, called UDP Multicast. With UDP, re-transmission is not part of the protocol and must be provided by some other means.

Figure 4 illustrates the difference between OTT delivery and IPTV delivery over Wi-Fi. This diagram shows the amount of bandwidth required to deliver an HD movie for an IPTV (in green) multicast video stream and for YouTube (in red.) YouTube delivers video bursts, relying on the client device buffer the video while more arrives later. In a Wi-Fi network the spaces between the bursts of video are opportunities for other Wi-Fi devices to get data from the Internet. IPTV, on the other hand, uses the same amount of bandwidth continuously. With no breaks in the data flow, this makes it difficult for other devices in the wireless home network that want to use the network and access the internet. The user experience in this case high radio signal strength but very low data rate.

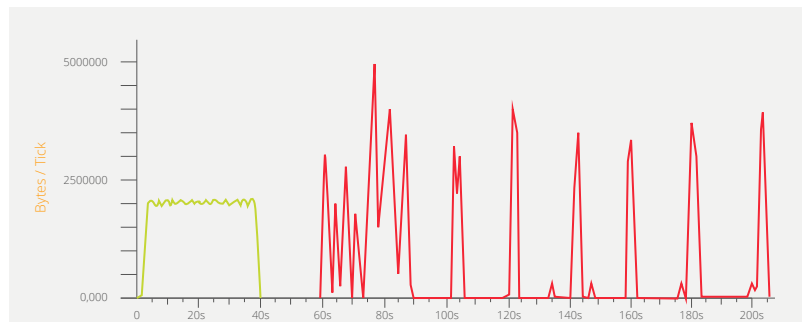


Figure 5: IPTV and OTT video delivery compared

A wireless access point for IPTV delivery must be able to sustain high bandwidth throughout the home. It must also be robust enough to withstand interference so as not to induce any errors in the delivery.

There are many decisions a wireless AP manufacturer makes in the design of a device. The quality of components, type of antenna, and sophistication of bandwidth and client management all impact AP performance. In the next sections we will examine how these design decision impact the performance of the wireless network, and understand what makes for an outstanding wireless access point.

## FREQUENCY MATTERS

The early wireless AP devices used the 2.4GHz frequency supported by the IEEE 802.11b/g/n wireless standard. This frequency is still used today, but is very congested because many wireless consumer devices use it. The 2.4GHz frequency is divided into 13 different 22 MHz channels. Unfortunately, many of these channels overlap interfering with each other. Also, the maximum transmit power that can be used in this frequency range is relatively low, just 100mW\*.

The other frequency used for wireless home access is 5GHz. This is less congested than 2.4GHz and the 20MHz channels do not overlap, cutting down on interference. Also, the transmission power that can be used is higher, between 200mW and 1000mW\*, depending on the channel used. The IEEE 802.11n and IEEE 802.11ac wireless standards can actually combined channels to create higher throughput. For example, two 20 MHz channels can be combined to create one 40 MHz channel with twice the bandwidth, and four 20 MHz channels can be combined to create one 80 MHz channel with four times the bandwidth.

A wireless AP that is able to leverage both frequency ranges and flexibly apply channels to optimize bandwidth can potentially deliver much better throughput. To understand more about the wireless frequencies refer to page 11 of the section entitled "Exhibit 2.4GHz and 5GHz wireless bands."

*\* Applies to Europe*





# THE TWO-PRONGED APPROACH TO WI-FI VIDEO QUALITY

There are two main approaches taken by wireless AP providers to ensure excellence in video delivery: maximizing the amount of bandwidth available, and optimizing the way the available bandwidth is allocated.

Bandwidth maximization is mostly a function of the physical design of the wireless AP and the quality of components used to make it. Bandwidth optimization is mostly about techniques for prioritizing which applications (such as video streaming) and clients get access to the available bandwidth. The next two sections will look at some of these approaches. More technical details can be found in the exhibits at the end of this paper.

## MAXIMIZE AVAILABLE BANDWIDTH

For a wireless device, one of the most important components affecting performance is the antenna and its ability to work with the RF interface to support multiple frequency bands. However, some wireless APs or clients use a switchable wireless configuration that supports one RF front-end interface and one antenna array. Controlled by software, the device can switch between the 2.4GHz or 5GHz band - but cannot use both bands at the same time. Better wireless products have separate antennas and wireless radios for each frequency band and support simultaneous communication in the 2.4GHz and 5GHz bands. In this configuration, the RF front-end and antennas optimize the RF for the corresponding frequency bands to maximize throughput.

In wireless APs today most devices use either a 2x2, 3x3 or a 4x4 antenna array.<sup>1</sup>

As you would expect, when it comes to antennas more is usually better. ARRIS compared two similarly configured Wi-Fi APs, one with a 2x2 and the other a 3x3 antenna array. The ARRIS test house was used to compare performance in a real world situation. The results are shown in Figure 5 below.

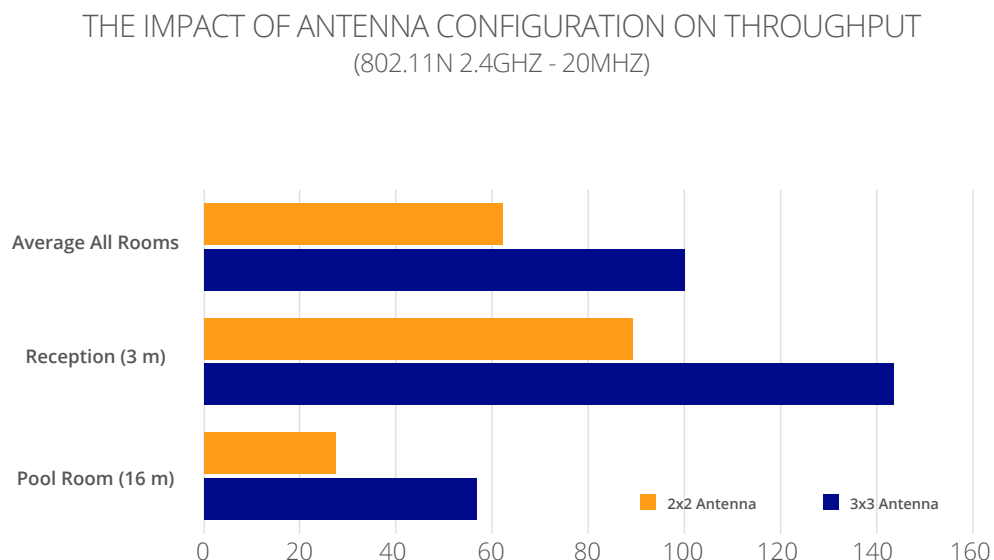


Figure 6: Impact of antenna design on performance

<sup>1</sup> A 1x1 antenna has an antenna attached to a single transmitter and receiver. A 2x2 antenna has two of these antenna/transmitter/receiver chains.



On average, the 3x3 antenna outperformed the 2x2 by 46%. Distance from the access point amplified the advantage of the better antenna. At a distance of 16 meters from the AP throughput on the 2x2 antenna fell to 26 Mbps while the 3x3 antenna was able to maintain 57 Mbps. For Multi-User-MIMO support in 802.11ac is a 4x4 antenna in the AP recommended.

The numbers of antennas in the client is less important. Tests show that 2x2 or 3x3 antenna arrays in wireless clients, especially in 802.11ac, provide similar or minimal improvements compared with 4x4 antenna arrays in the client.

Many APs transmit uniformly in all directions around the antenna. This omnidirectional antenna configuration is wasteful because the transmission power is not directed towards the client. Other wireless networks receive this signal as interference. More sophisticated devices use a signal processing technique called beamforming to direct more of the transmit energy in the direction of the clients connected to the AP. Earlier approaches to beamforming used smart antennas to gather information about the location of the clients and keep the transmission energy focused on them at all times. Newer devices use explicit beamforming.

Explicit beamforming is part of the IEEE 802.11ac standard and resolves the interoperability problems seen with 802.11n proprietary implementations. This beamforming technique uses a sounding procedure with Null data packets to get feedback from the wireless clients and calculates the optimal steering matrix for each client. This is a dynamic process, with continuous adjustments to adapt to changing environments. Explicit Beamforming is required for Multi User MIMO support.

## OPTIMIZE BANDWIDTH ALLOCATION

Choosing the right hardware should maximize the bandwidth available to deliver the video. However, all the bandwidth in the world is no good if you can't access it. One of the most complex tasks handled by wireless APs is allocating time to each client that is connected to it. Simply put, if one client hogs all the airtime all the other clients will experience bad performance.

There are two main ways that better wireless APs handle the allocation of airtime: reserving bandwidth for specific applications (like video), and managing the clients so that slower, marginal devices do not spoil the performance for everyone.

## BANDWIDTH RESERVATION

The simplest approach to bandwidth reservation is to allocate high priority data, like video, to a separate frequency band than the rest of the Internet traffic. Some APs reserve the 5 GHz band for video and push the rest of the Internet traffic onto the more populated 2.4 GHz.

APs also support Wi-Fi multimedia (WMM). This standard defines how to tag time sensitive traffic like video and ensure that it is prioritized over other data types. WMM works well in wireless networks where there is enough airtime available to transmit all the requested data from the clients. Unfortunately, it does not work well when there are too many clients requesting too much data.

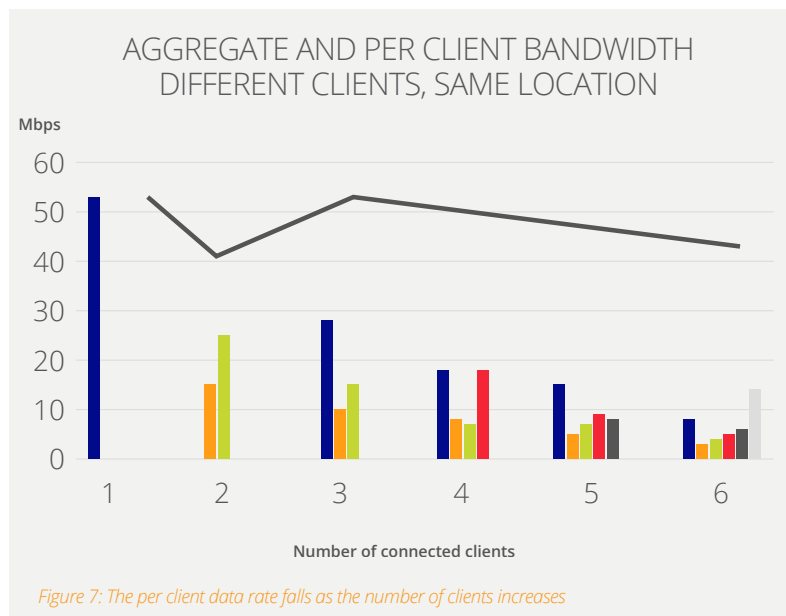
The problem with WMM is that it is not fair to all clients: in marginal situations video can block all other data access. WMM only knows about media. It is unable to apply any QoS management to the rest of the data traffic. An example of the impact of WMM QoS can be found below in the section entitled “The impact of WMM QoS” on page 16.

New Smart QoS systems<sup>2</sup> allow an operator to classify many different types of Internet traffic and assign priorities to each. This allows the wireless AP to more equitably manage the airtime between clients.

## CLIENT MANAGEMENT

Given that wireless bandwidth and airtime are finite resources it only makes sense that the more clients that associate with an AP the less bandwidth and airtime available to each (for a detailed explanation of this problem see “Client management” on page 8). As Figure 7 shows, even adding just one extra client can have a dramatic impact on overall bandwidth available to each client.

Even worse, poor performing clients can have a dramatic negative impact on every other device connected to the AP. A device receiving data at 10 Mbps will take up to 10 times longer to receive a file, and consume up to 10 times more airtime, than a device capable of connecting at 100 Mbps. One way to handle this situation is to create two access points, one using the 5 GHz frequency band and the other using 2.4 GHz. Slower clients can automatically be associated to the 2.4 GHz AP. In this configuration faster clients are not impacted by the slower. To understand more about this issue see the section “Dedicated bandwidth” on page 13.



When a fast client is at the very edge of Wi-Fi coverage it starts to behave like a slow client. That is, it takes much longer to download files because, as we saw earlier, the further away from the AP you are a lower the effective bandwidth you have. In this case, a better wireless AP can use video stream protection (VSP) to ensure that someone watching video closer to the AP is not adversely impacted by a client at some distance from it. VSP detects a multicast video stream and reserves bandwidth and airtime to ensure that it can be delivered. If the AP detects that there is insufficient airtime to service both a client viewing the video stream and a far flung client it automatically drops the marginal device.

<sup>2</sup> To understand more about smart QoS see the section “Internet Application QoS” on page 16.

## THE IMPACT OF THE WIRELESS CHIPSET

As shown in Figure 5 the antenna configuration has a dramatic impact on the throughput of the wireless AP. However, many of the techniques discussed so far affecting bandwidth availability and allocation are implemented the wireless chipsets which AP manufacturer base their devices upon. Companies like Broadcom, Quantenna, Atheros, Qualcomm and MediaTek create their chipsets optimized for specific markets. For example, some chipsets that target the consumer market have power consumption or cost as a primary concerns while others optimize for coverage and performance.

In other words, the chipset an AP manufacturer uses has an enormous impact on the performance of the device. That said, a manufacturer still has plenty of room to improve the performance of a given chipset.

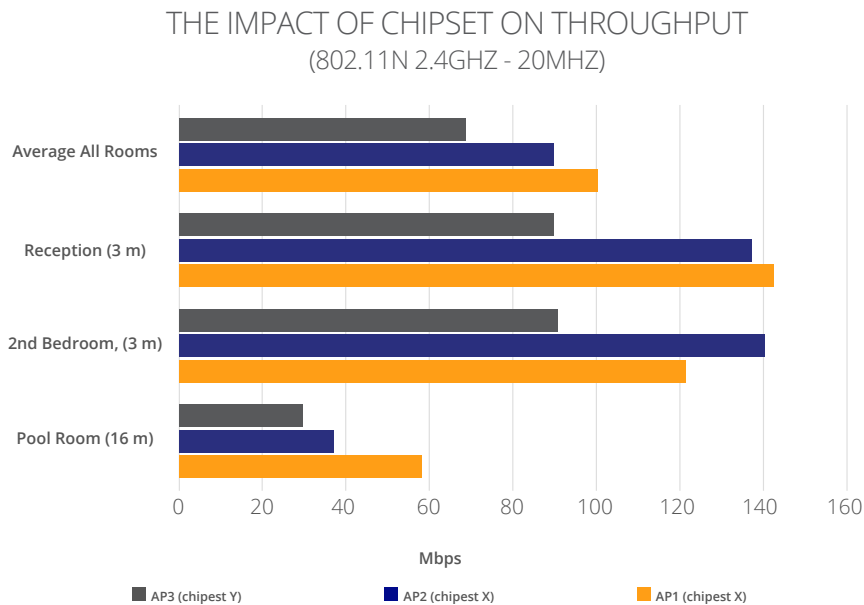


Figure 8: The impact of wireless chipset on AP throughput

Figure 8 shows the performance of 3 wireless APs from 3 different vendors in 4 different locations of the ARRIS test house. AP1 and AP2 both use the same chipset, and AP3 uses a chipset from a different vendor. In all rooms, AP3 delivers lower throughput (a third less on average) than the other two devices, but the difference between AP1 and AP2 is more complex. In the reception area, close to the AP, both devices perform almost identically. In the pool room, AP1 delivers 58% more throughput than AP2, while upstairs in bedroom 2 AP2 is 25% better than AP1.

These test results illustrate clearly that an IPTV operator needs to select a wireless AP very carefully. Operators need to ensure they choose a device with a chipset optimized for the delivery of multicast video and a design that works well in their customer's home.

## IEEE 802.11AC WIRELESS STANDARD

The new deployed wireless standard offers improvements in bandwidth and better interoperability because some of the proprietary implementations used in 802.11n became in 802.11ac standard. The transmission power and frequency band has not changed. Therefore we cannot expect better coverage but the throughput at the edge of the coverage is improved and users experience reasonable speed in areas with high attenuation. The main new features of IEEE802.11ac are:

- Theoretical throughput up to 1.7 Gbit/s with 4x4 antenna and 80 MHz channel
- Intended to be used in 5GHz band only.
- 256 QAM modulation. The modulation increased from 64 QAM to 256 QAM. The density of data over the air increase but this higher Modulation Coding Schemes (MCS) is used in close or medium distance to the AP only.
- Wider channels: 80 and 160MHz to improve spectral efficiency. Channel combining increase the bandwidth. 80MHz channels (combine 4 x 20MHz channels) are standard today. 160MHz is not used yet. The down side is that the number of combined channel reduces the numbers of non-overlapping APs. This is the number of AP which can communicate without interfere each other.
- More spatial streams: Up to 8 in Single User-MIMO and 4 in Multi User-MIMO. This increase the spectral density but requires more antennas in the AP.
- Multi User MIMO (downlink) is not widely implemented today. Most of the vendors introduce this feature in next generation 802.11ac chip set. This feature allows an AP to communicate to multiple clients at the same time. Up to four clients are allowed in one MU-MIMO group. This feature can double or triple the bandwidth but MU-MIMO works in close or medium distance to the AP only and MU-MIMO needs to be supported in AP and client.

# CONCLUSIONS

As consumers continue to embrace video consumption over connected devices in the home, their demand for television quality video on those devices will increase. Consumer grade wireless access points may work adequately for Internet streaming, but they are not optimized for the demands of multicast IPTV video delivery.

The only way to ensure an IPTV customer receives video on their connected device with the quality and reliability of the subscription television service they have grown to rely upon is to invest in a high quality wireless access point. In order to meet these exacting standards, the following points are important when making a decision for wireless equipment:

- Support for both 2.4GHz and 5GHz wireless frequency bands in the home . (especially important on APs)
- A 3x3 or 4x4 antenna arrays coupled with a transmitter subsystem capable of using beamforming and MIMO techniques should be supported.
- A Higher number of antennas increases spectral density (especially important on APs)
- Wireless standard IEEE 802.11ac increase the bandwidth in the wireless network
- Type and location of the antennas. External, not printed on the board and away from disturbers from the PCB. This can help decrease interference.
- 5GHz radio must support U-NII-2 Extended band because the maximum allowed transmission power is in this band 1000mW.
- Bandwidth reservation, basic Airtime management and WMM to guarantee clients sufficient throughput to receive multicast video throughout the home
- The AP and Client must meet the ETSI regulation (for Europe) This must include DFS certification

Other considerations:

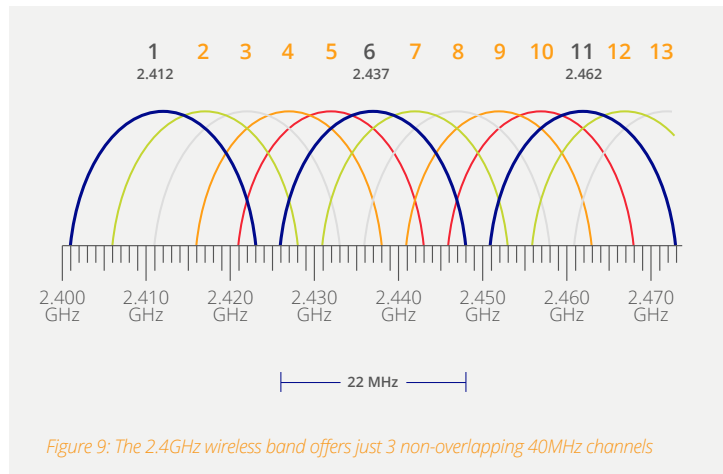
- Client management to ensure slow or peripheral devices do not degrade performance of clients receiving video
- Built around a wireless chipset that puts the optimization of IPTV video delivery ahead of other constraints such as power consumption and cost.

Only with a device built with IPTV delivery in mind from the start will operators have a home device capable of supporting the video needs of their customers today and into the future.

## EXHIBIT: 2.4GHZ AND 5GHZ WIRELESS BANDS

The 2.4GHz band is divided in 13 channels. Two channels can be aggregated to form one 40MHz channel, but only three of these aggregated channels are not overlapping. That means in a dense wireless environment, like an apartment complex, only three APs using 2.4GHz can transmit without interference. Any additional APs trying to use 2.4GHz in the same location will cause interference. The 2.4GHz band is the most congested because many consumer devices, public hotspots and low cost APs use this frequency band for wireless transmission. Also, it should be noted that the maximum transmission power is limited to just 100mW in Europe.

The 5GHz band can be used as an alternative to 2.4GHz band. IEEE 802.11n and IEEE 802.11ac wireless standards allow for the aggregation (combination) of channels to create a higher throughput channel. For example, to create a single 40MHz channel two 20MHz channels can be combined. Similarly, an 80MHz channel can be created from four 20MHz channels. Figure 10 shows that channels do not overlap in the 5GHz band. Though nine access points can transmit without interference in 40MHz configuration, most vendors restrict this to seven because channels 120-128 may be used by radar systems. The maximum transmission power in this band is higher than 2.4GHz. Channel 36-64 allows a maximum transmit power of 200mW, and channels 100-140 a maximum of 1000mW. A good access point should be capable of transmitting in the upper band with up to 1000mW transmission power and should be able to detect when interference is occurring and automatically switch to a better channel.



U-NII Band	5015	U-NII-1		5015	5015	U-NII-1		5015	5475	U-NII-2 Extended Band							5725			
ETSI Band (MHz)	5150				5350				5470								5725			
Center Frequency (MHz)	5180	5200	5220	5240	DFS	DFS	DFS	DFS	5500	5500	5540	5560	5580	5600	5620	5640	5660	5680	5700	
IEEE Channel	36	40	44	48	52	56	60	64	100	104	108	112	116	120	124	128	132	136	140	
20MHz	■				■				■				■				■			
40MHz	■		■		■		■		■		■		■		■		■		■	
80MHz	■				■				■				■				■			
160MHz	■								■								■			
													Weather Radar							
													Not used							

Figure 10: The 5GHz frequency band is less congested and allows more non-overlapping channel aggregation than 2.4GHz

Just because an AP supports 5GHz, however, doesn't mean it is doing so correctly. The requirements for using the 5GHz band in Europe is defined in the ETSI document EN 301 893. In 2013, the R&TTE (Radio & Telecommunication Terminal Equipment) verified 101 wireless devices against this standard and checked compliance with dynamic frequency selection (DFS.) This investigation revealed the following:

- 37 devices operate in the lower band only and use a limited band (5150-5250MHz) or transmit below the 200mW maximum
- Just 18 wireless APs (28%) were in compliance with EU regulations.

Some of the violations reported by R&TTE included operating in ranges outside of the permitted frequencies, failing to implement DFS, and failing to provide Declaration of Conformity documents.

## EXHIBIT: TECHNIQUES IN MAXIMIZING AVAILABLE BANDWIDTH

### ANTENNA CONFIGURATION

The antenna design is a critical part of the wireless AP performance. Decisions made early on in the design of the devices determine how well it will perform. ARRIS testing proves that the same wireless chipset can behave differently depending on the antenna used and the layout of the printed circuit board (PCB). For example, antennas printed on the PCB board are very cost effective, but they provide low gain which dramatically reduces the coverage area. A much better implementation is to separate the antenna from the PCB, although it can still remain the unit's enclosure.

Another critical component of the RF (radio frequency) design is the Low Noise Amplifier and Power Amplifier. Some wireless APs are not able to transmit with the maximum allowed power because of poor design or poor quality of these components. Naturally, in these circumstances the transmit area is greatly reduced.

New wireless interfaces support multiple input multiple output (MIMO) antenna systems. The spectral density and maximum possible throughput increase with the number of antennas. MIMO systems have much higher spectral efficiency compared to SISO (single input single output) antenna systems. Higher spectral density improves wireless signal power which, in turn, increases throughput and lowers data error rates. All highly desirable characteristics for an IPTV delivery systems.

#### A SINGLE ANTENNA DOES NOT PROVIDE A ROBUST DELIVERY SYSTEM

Number of antennas (spatial streams )	IEEE 802.11n 40 MHz	IEEE 802.11ac 80MHz
1 x 1	150 Mbit/s	433 Mbit/s
2 x 2	300 Mbit/s	867 Mbit/s
3 x 3	450 Mbit/s	1300 Mbit/s
4 x 4	600 Mbit/s	1700 Mbit/s

<sup>3</sup> Spectral density is a measure of the energy contained in signal. The higher the density, the higher the energy. Higher energy is associated with improved penetration through walls, better overall signal reach, and lower data error rates.

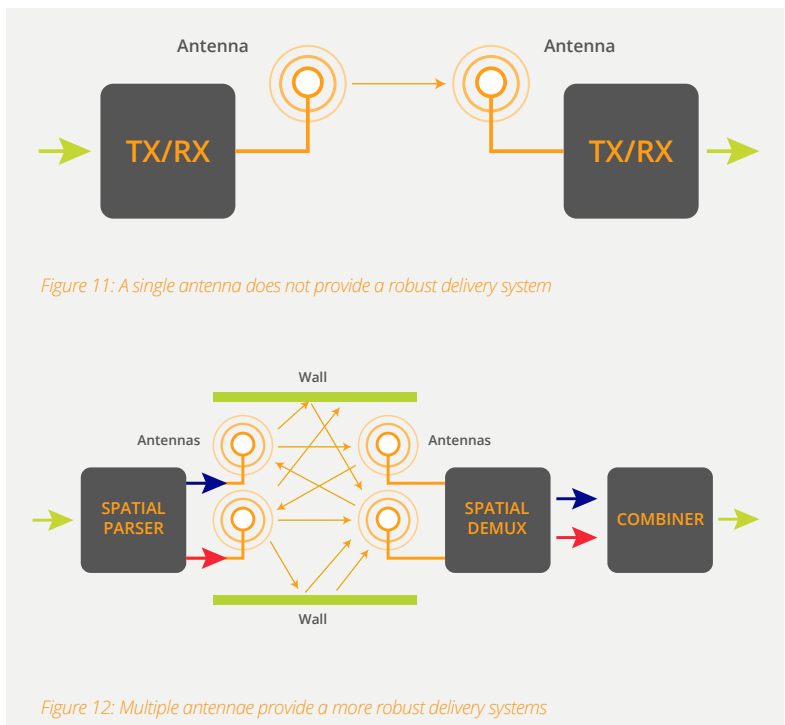
<sup>4</sup> In MIMO data transmission, multiple wireless signals are being transmitted and received simultaneously. The signals being transmitted by the several antennae are multiplexed together by using different spaces within the frequency range. These spaces are called spatial streams.



A device with just one antenna has low spectral density, provides no data redundancy and one spatial stream only. There is little robustness in a 1x1 antenna arrangement.

A device with multiple antenna provides higher spectral density with multiple spatial streams. The spatial streams take advantage of reflections from walls. This increases the throughput and reduces packet loss, resulting in a much more robust wireless delivery system. The best wireless system use a 4x4 system. The coverage and throughput increase again.

Figure 5 shows the improvements in performance that can be achieved by using a 3x3 antenna rather than a 2x2 one.



Multi-User MIMO is another technique available in IEEE 802.11ac which can improve the bandwidth. Traditional 802.11 wireless communications is based on Time Division Multiplexing (TDM). The AP can communicate to one client at a time and all clients share the total amount of available transmission time (airtime).

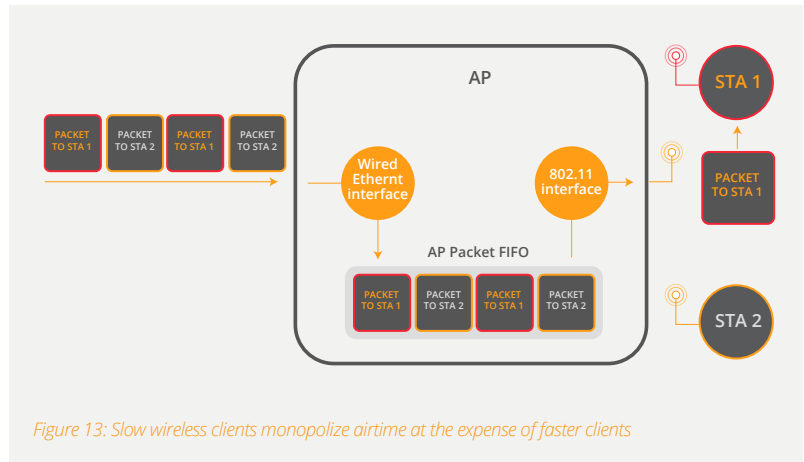
The feature MU-MIMO allows an AP to transmit up to four clients at the same time. Special beamforming reduce the interclient interference. The AP has more airtime left for other wireless clients and the bandwidth in a MU-MIMO group can be doubled or tripled. It needs to be noted that MU-MIMO works in short or medium range to the AP only. The AP changes automatically to normal MIMO when the attenuation increases. All clients in a MU-MIMO group must support this feature but MU-MIMO and non MU-MIMO clients can co-exist in a wireless network.

# EXHIBIT: TECHNIQUES IN OPTIMIZING BANDWIDTH ALLOCATION

## DEDICATED BANDWIDTH

Some operators use a second external access point or a gateway with two independent wireless radios to serve video applications. Often the 2.4 GHz band is used for normal internet traffic and 5GHz reserved for video delivery. This approach protects the video service from being affected by other data requests or slow 802.11n clients.

Why do slower clients impact performance for everyone? Figure 13 illustrates the problem. Consider the situation where a wireless AP is talking to a client (STA2) capable of 10mbps communication and a fast client (STA1) capable of 100mbps on the 5GHz band. The wireless AP talks to both STA1 and STA2, but because STA2 is limited to 10mbps it takes up much more airtime to receive its packets of data than STA1. This means STA1 gets less time to receive its data and its potential throughput is reduced.



However, if STA1 and STA2 connect to different APs the slower client can't impact the faster one. Now it doesn't matter how long STA2 takes to receive its data, STA1 will have all the airtime it needs.

To illustrate the potential improvement in throughput for all clients, consider the two configurations in Figure 14. In setup 1, all the wireless clients are connected to the same AP. In setup 2 the slow clients are associated with AP2 and the fast clients with AP1.

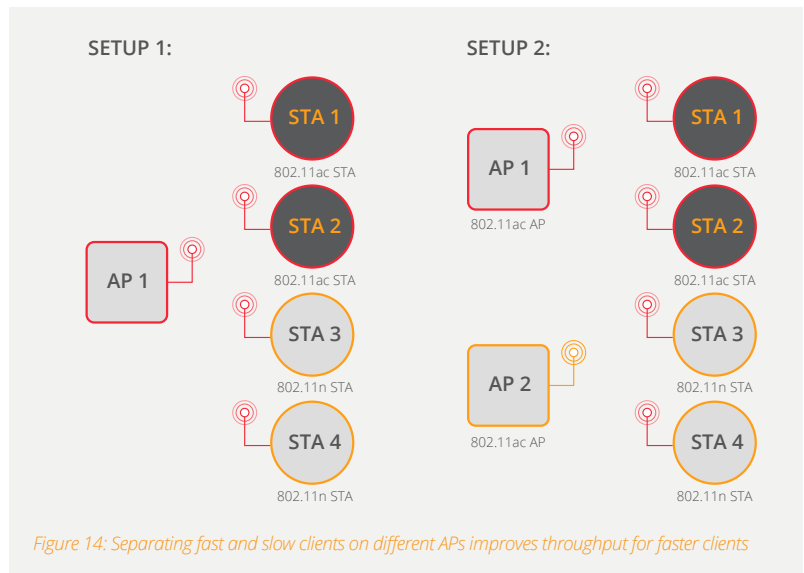


Figure 15 shows the difference in performance between setup 1 and setup 2. The throughput in setup 2 is 50% higher. The overall airtime doubles when using two APs and associating slower clients to a single AP. The fast clients have more airtime available and can transmit with much higher throughput. This arrangement improves the robustness of wireless service and helps improve video services in situations where signal attenuation increases.

	STA1 (802.11ac)	STA2(802.11ac)	STA3(802.11n)	STA2(802.11n)
Setup 1	44Mbps	41Mbps	38Mbps	38Mbps
Setup 2	86Mbps	87Mbps	46Mbps	46Mbps

Figure 15: Table showing throughput improvements achieved by separating fast and slow clients

## AP CLIENT AIRTIME MANAGEMENT

To illustrate why careful management of client airtime must be included, ARRIS performed a test with one access point using 2.4GHz and connecting to three clients; a smartphone, tablet and wireless set-top-box. Using the ARRIS test house, the STB was placed on the second floor. Multicast video was started and played normally with no packet loss or disturbance. The smartphone was placed in the mid-range of reception and a low bandwidth YouTube video started. Again, the video played normally with no apparent errors or problems.

After a few seconds a file download was initiated from the tablet. With the addition of the tablet traffic the wireless system exceeded the maximum available airtime and all clients experienced packet loss.

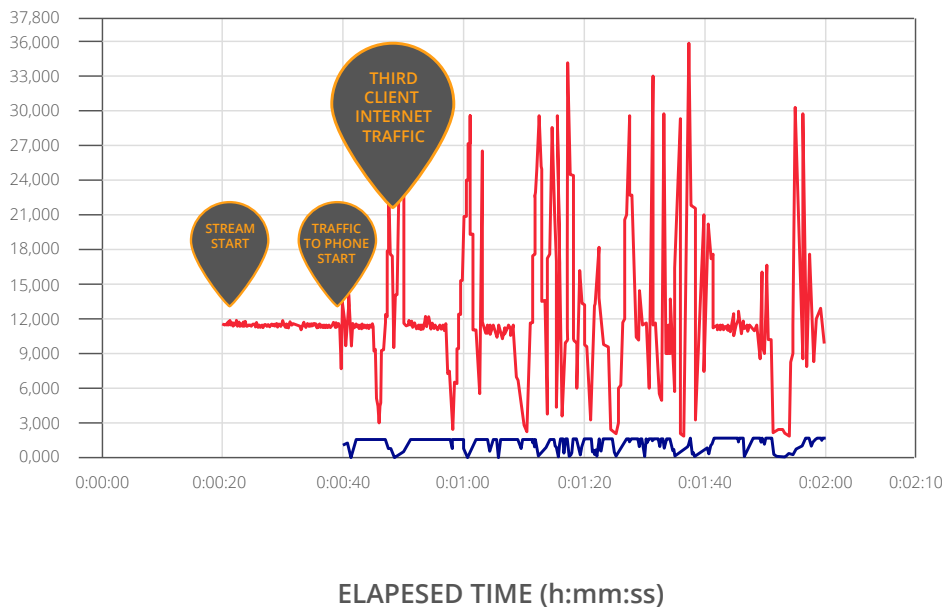


Figure 16: When the maximum airtime available is exceeded all clients experience packet loss

Figure 16 shows how the STB throughput went up and down when the tablet started its wireless transmission to receive the requested file download. Figure 17 shows the resultant 80% packet loss. This high packet loss caused the video streaming to the STB to freeze.

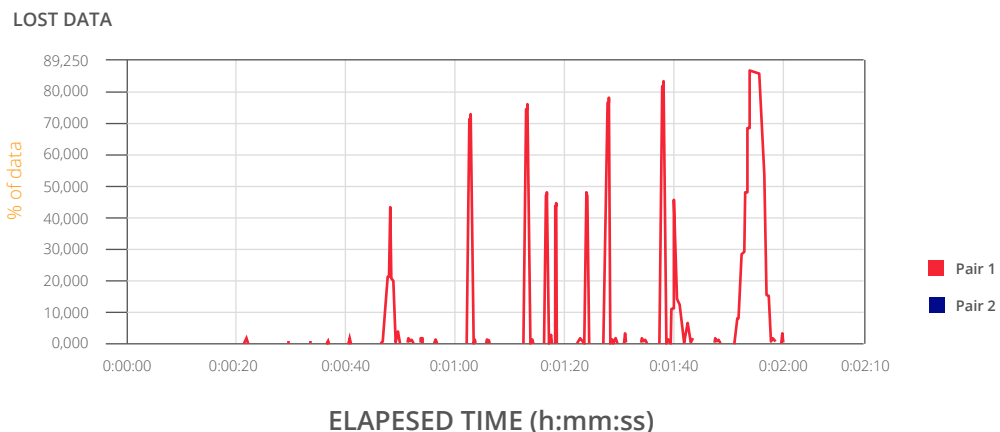


Figure 17: When airtime is oversubscribed packet loss is the inevitable result

## THE IMPACT OF WMM QOS

To illustrate the impact of WMM the video stream from the previous example was tagged with DSCP Assured Forwarding QoS and the previous test repeated. The results are shown in Figure 18.

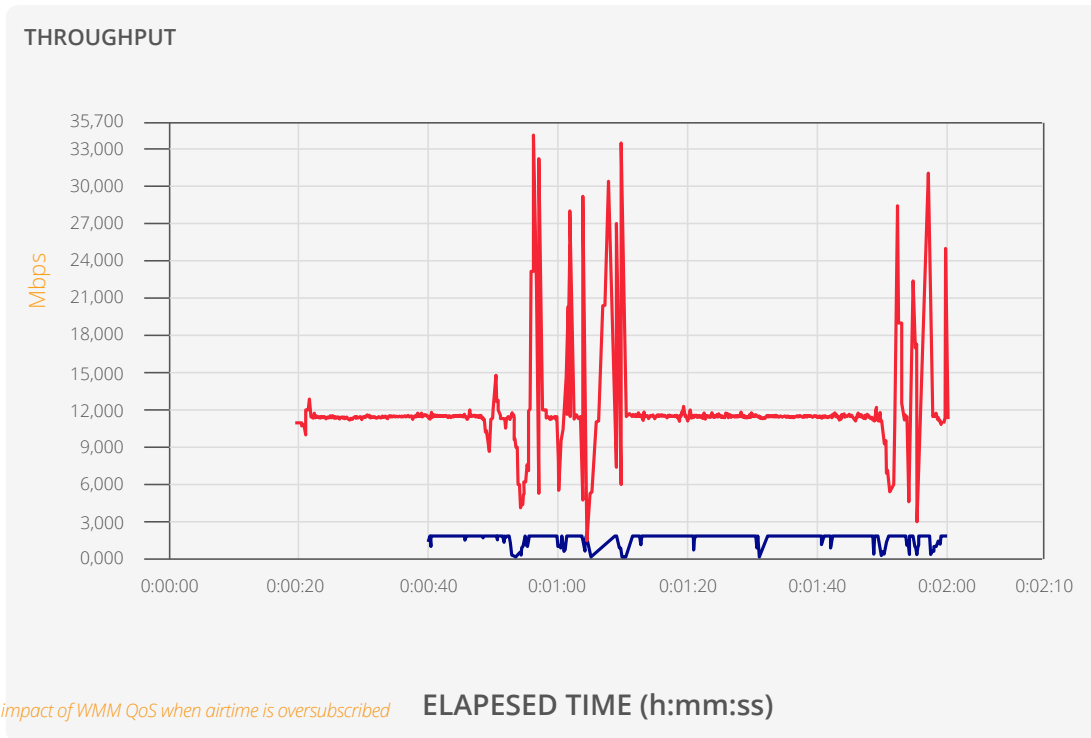


Figure 18: The impact of WMM QoS when airtime is oversubscribed

The STB and smartphone videos were started and performed as before. However, when the download to the tablet was started the WMM system assigned more airtime to the 12Mbit/s video stream. The throughput and video performance was maintained to the STB. Unfortunately, wireless access at the tablet was almost completely blocked.

This illustrates the limitations of WMM QoS. While it can solve some of the issues with QoS protected clients, others without QoS cannot access the wireless network anymore. Multicast streams can take the entire bandwidth of a wireless system when a wireless STB client is further away from the AP or in high attenuation environment.

## INTERNET APPLICATION QoS

Smart QoS systems can detect when airtime is oversubscribed and maintain stability by discarding packets. A smart QoS system guarantees clients equitably receive airtime and that packets are discarded fairly. To do this, the system must be able to sort all the packets into multiple queues, ordered by the type of Internet application, before they go into the WMM queue.

Internet application QoS allows the classification of Internet traffic based on its characteristics. ToS (type of service) bit marking or VLAN priority 802.1p is not required for this classification process. The access point or gateway is able to detect the type of data and assign it a specific internal priority dynamically before forwarding to the wireless system. In this way, an application like video can be guaranteed to receive more airtime without completely blocking another, less critical, application.

This type of QoS is self-learning and can be controlled by the operator, which can update new characteristics via remote management of the AP.

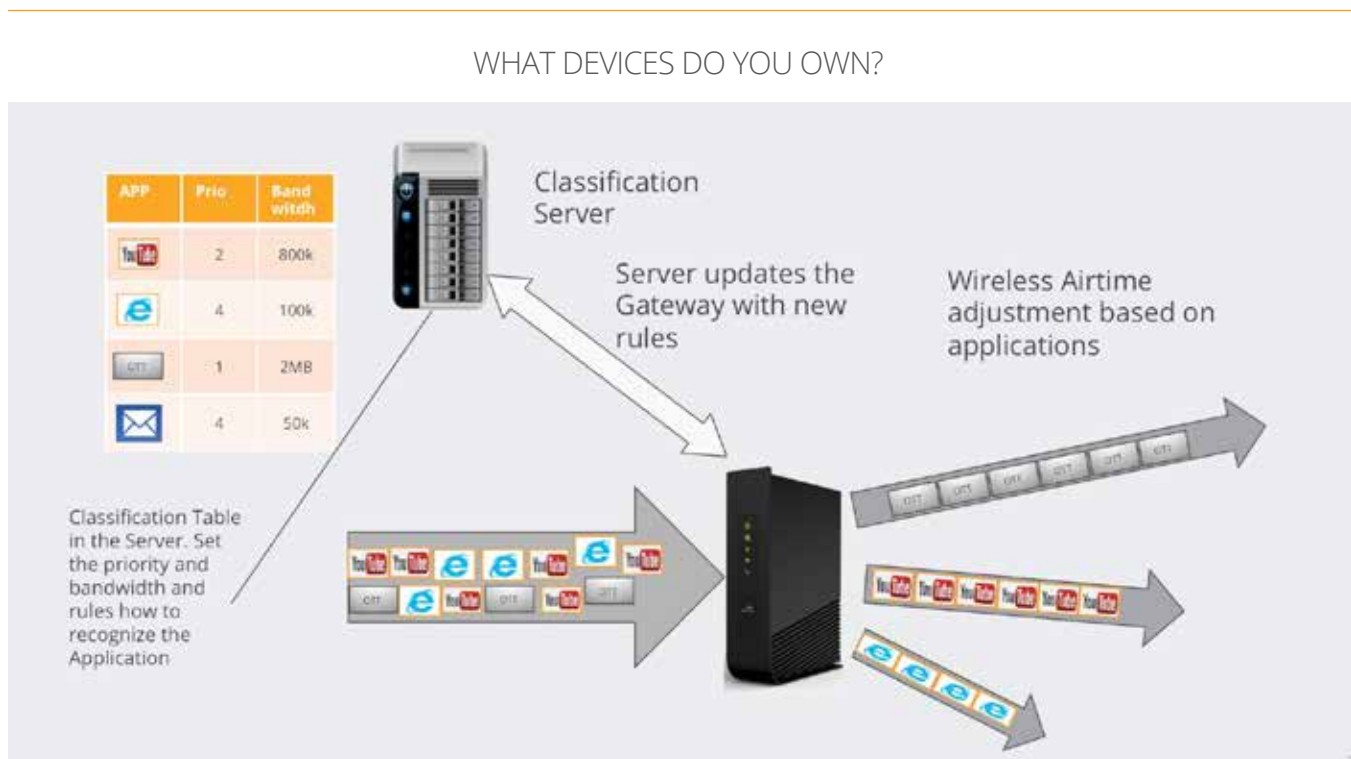


Figure 19: Smart QoS applies airtime priorities dynamically based on operator controlled criteria

- i Arris, *Consumers Want Entertainment on Their Terms*, Arris, May 18 2014, <http://www.arriseverywhere.com/2014/05/entertainment-on-our-terms-the-case-for-personalization/> (accessed on 3/9/14)
- ii Colin Dixon, *BBC iPlayer Tracker*, nScreenMedia, <http://www.nscreenmedia.com/bbc-iplayer/> (accessed on 18/8/14)
- iii Convia, *2014 Viewer Experience Report*, Convia, Q2 2013, <http://www.convia.com/vxr-home/> (accessed on 18/8/14)
- iv Adco R&TTE, *REPORT ON THE 5TH JOINT CROSS-BORDER R&TTE MARKET SURVEILLANCE CAMPAIGN (2013) WLAN 5 GHz*, adco R&TTE, October 16 2013, [http://ec.europa.eu/enterprise/sectors/rtte/files/5th-rttems-report\\_en.pdf](http://ec.europa.eu/enterprise/sectors/rtte/files/5th-rttems-report_en.pdf) (accessed on 3/9/2014)