



# 360 Degrees of Video Opportunity

## An Operator Gateway into Virtual Reality

eBook brought to you by Harmonic and Viaccess-Orca

Authored by Ben Schwarz, CTOi Consulting



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# Executive Summary

How can we cross the virtual chasm to propel VR360 out of the hype cycle trough it is in now?

Today, users are sometimes underwhelmed by VR360 video quality while operators are often overwhelmed by the high bitrates required. Social capabilities and immersive sound are just starting to be integrated into VR.

So why are key stakeholders already aggressively pushing the VR market?

The industry is developing solutions for these issues. In this eBook about premium immersive video experiences (aka VR360), we dive into user experience issues and how to make video delivery more efficient, based on a new video technique called tiling. This is the only working

solution to address the four-way compromise between latency, bandwidth, processing and storage. We will bring you up to speed on what a “premium VR360 video experience” is. In addition, we look at the promise of immersion and to what extent consumers really want it, explaining the key VR concepts. For a more complete set of definitions, visit: [VR Industry Forum: Lexicon](#).

A comprehensive view of all aspects of VR can be found on the [DVB Study Mission on Virtual Reality](#).

We don't know when VR360 will become mainstream, but it's well worth actively investigating now. VR has already started to disrupt entertainment, video and user interfaces.



## Video 360

Video presented in 360° requiring a head-mounted display for premium experiences.

# The Immersive Promise

The wow factor is undeniable the first time you experience high-quality VR with immersive video and audio. There's a jaw-dropping sense of having glimpsed the next-generation, immersive entertainment. You must experience this yourself to realize how profound the shift is.



*Even with our first VR experiment two years ago, using just a 180° field of view, feedback was already a unanimous 'wow!' "*

**Andy Gower, Head of Interactive TV Research, BT**

Although experiments show greater emotional response with VR than with other media, no hard data explains to what extent ordinary people, beyond the early adopters, care about this enough to pay for it. Billions of dollars are already being spent by tech giants to bring this exciting new user experience to the masses. But what is it? And can we already say whether people want it?



*We've been setting up temporary VR demos at points of sales for two years now.*

*The queues haven't diminished; Italians are still eager to try this."*

**Massimo Bertolotti, Head of Engineering and Innovation at SKY Italia**

In July 2017, BBC R&D published findings from a 12-week study with a sample of the UK population<sup>1</sup>. The BBC sees VR as a next step in the mass market storytelling mediums it has pioneered since 1922. But, as for all public broadcasters, the question of mass adoption is crucial. The study shows that people's initial response is very enthusiastic. Although consumers are initially drawn to the more extreme experiences (i.e., horror, roller coasters), over time they find a wider palette of genres to enjoy.

BBC researchers were surprised that participants frequently came back to watching traditional 2-D widescreen content in a virtual cinema. This shows we need to consider a transition to VR360 that caters for a 2D viewing experience in a VR environment. In addition, as stakeholders have requested, we also need to deliver an entry-level VR360 experience on flat screens, using the magic window concept where the screen is the Point of View (PoV) using existing controllers such as the keyboard for a desktop, the remote control for a TV or just moving the mobile device around.

The magic window is emerging as a gateway to full-blown VR, allowing users to interact with VR360 content on 2D screens without the need for headsets or other dedicated hardware.

## **HMD**

A Head (or Helmet) Mounted Display has a small display optic in front of each eye and can be tethered to a video source



*Even the most hardened journalists were in tears at this year's Cannes Film Festival after crossing the U.S. border illegally from Mexico in a VR experience created by 'Birdman' director Alejandro G. Iñárritu."*

**Morgan Bouchet,**  
Head of VR, Orange

Beyond the mere transmission of information, VR360 heralds the coming of the "experiential age" to push the "informational age" to a new level. True immersion enables Google Earth, for example, to provide new ways to discover the Earth.



*VR360 gives users front-row experiences for events they couldn't otherwise go to."*

**Alex Berriman, eSports and VR Specialist at PCCW Global**

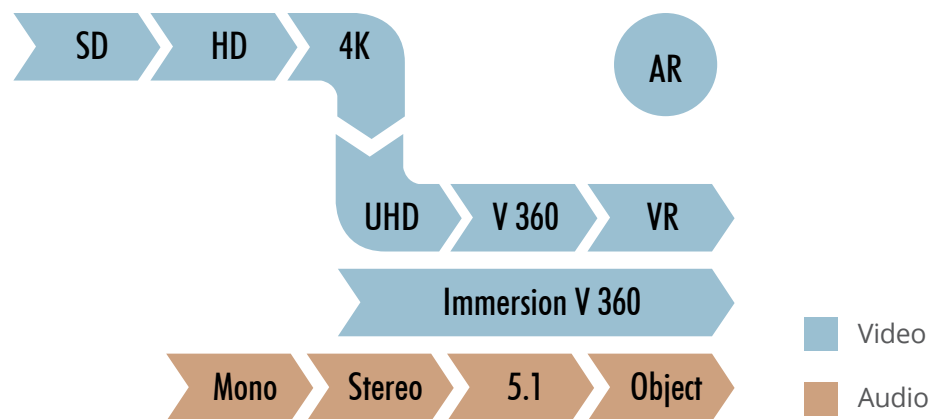
## Premium VR360 video experiences

360-degree video can be streamed directly from Facebook or YouTube onto a TV with a 360-capable player or a mid-range smartphone and watched by turning the phone around. This is amusing the first time you try and can whet consumers' appetites for VR at no cost to them, but it is neither truly immersive nor premium.

360-degree video alone is a key component, but the interactivity, immersive audio and sensor-rich HMDs define the full experience that we will call "premium VR360 video experience." In today's connected world HMDs provide viewers with the all-too rare opportunity to engage with content, free from distraction.

Today's designers see VR and Augmented Reality (AR) as a new, hyper-immersive experience that generates more spontaneous emotions. They are inventing a new grammar and symbology<sup>2</sup> for VR. Being able to manipulate the media through a PoV within the scene changes the user's role from passive spectator to active participant. Users feel they are truly present. An early use case for VR360 is having a front-row seat at a live event.

Entertainment has incorporated immersion for some time, yet UHD video with 4K resolution, HDR color and next-gen audio have just started to arrive. While HD offers a much more immersive experience than SD television, 360-degree video will be a giant step forward, allowing the viewer to truly enter the video experience.



**Figure 1.** The AV trend toward immersive experiences



*360-degree video is an entry into the VR domain."*

**Sam Rosen, Vice President,  
Consumer at ABI Research**

Early adopters like NowTV in Hong Kong have reported incredible user excitement at its live demos, described on page 13. Experts like VR Industry Forum (VRIF)'s<sup>3</sup> President Rob Koenen confirm that users in all the trials they've been involved in are truly excited. But he also warns that operators must tread carefully, not overselling prototype services as early adopters will only accept being underwhelmed so many times before losing their enthusiasm.

We are still learning what makes a virtual reality experience plausible between the wideness of field of view, higher resolution, lower latency or overall coherence<sup>4</sup>. For example, while it is already clear that immersive sound vastly enhances 360-degree video's wow factor, it should be deployed carefully to avoid distracting users from the content itself.



*Being surrounded by video and sound is part of a truly immersive experience; however, users will tire of having their attention drawn away from what's in front of them too often, especially in the case of 360-degree video."*

**Kévin le Jannic, Emerging  
Business Leader at  
Viaccess-Orca.**

Although low background noise coming from all around is a great VR360 feature, Viaccess-Orca have learned with their Virtual Arena product that distinct audio that catches

your attention, and when not coming from in front, should be used sparingly.

The idea that a killer app will kick start a new disruptive market is attractive, although chasms can also be crossed with tiny steps at a time.



*We need a killer app like Pokémon Go, but one that has true AR capacity to analyze the environment, scale objects and take moving objects into account, not just location as in the previous game. Such a killer app could well come from Apple".*

**Morgan Bouchet,  
Head of VR, Orange**

There are, of course, stakeholders with a vested interest that firmly believe a single killer app will usher the virtual market into reality. Unsurprisingly, Facebook considers people to be the killer app of virtual reality with social media as the enabler. The company is still investing billions in VR after spending an initial \$2 billion for Oculus even before the device shipped.

## **VIRTUAL REALITY**

Simulation of a user's physical presence in a virtual or imaginary environment

# Virtual Business Becoming Real

The billions of dollars invested by consumer tech giants Facebook (Oculus Rift), Samsung (Gear VR), Google (Daydream View) Sony (PlayStation VR) and Microsoft (HoloLens) show that consumer tech is convinced that growth in the VR market is imminent. Facebook alone has acquired 11 AR/VR companies since 2013, while HTC/Vive has stakes in over 28 startups<sup>5</sup>.

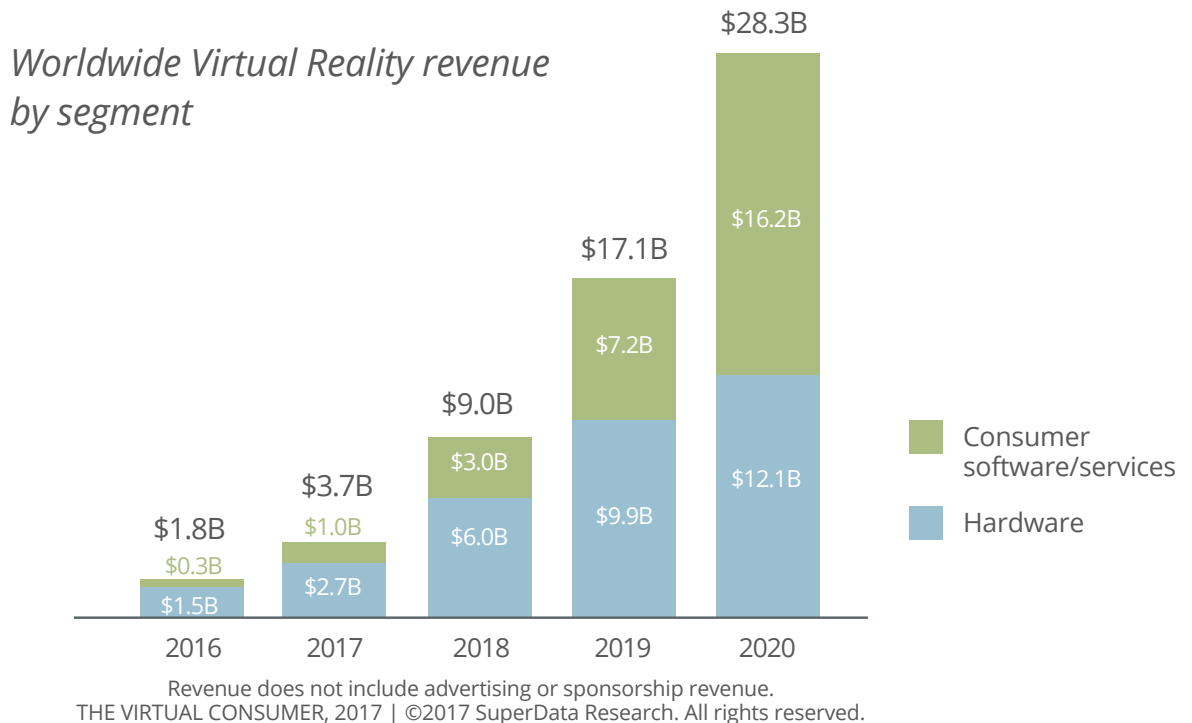
App store statistics show downloads in the hundreds of thousands for VR360 apps, related to major sporting events.

New segments like VR arcades are being experimented with by entertainment giants and startups alike<sup>6</sup>. The market for premium VR360 video experiences will greatly benefit from the dynamism and robustness of the gaming segment, even if that's not its primary target because

the video component isn't central in games. Application domains that stand out – see the DTVE survey<sup>7</sup> (Figure 2) – are live sports and live music. All operators we spoke to for this eBook concur, with only Orange yet to trial live sports because it is looking to first bring the video quality up a notch.

In the nascent VR ecosystem, many startups are busy inventing the world of tomorrow. Live sports specialist NextVR, for example, has raised over \$115 million in a bid to create long-form virtual reality content in broadcast quality. As always, with disruptive new technology, there is a hype cycle (Figure 3). As we have already experienced a peak of expectations in the last two years, followed by the “trough of disillusionment,” the only way to go now is up.

## VR revenue will total almost \$30B by 2020 - 15 times what it was in 2016



**Figure 2.** Projected size of the augmented and virtual reality market 2016-2020

# Monetizing the Premium Content Experience

Early adopter operators we spoke to use VR360 as an add-on to enhance brand and loyalty. Greater immersion creates opportunities for more emotions for example to develop brand loyalty. Direct ARPU will come later.



*VR360 content can be monetized within a few years just like TVOD and SVOD are today."*

**Morgan Bouchet, Head of VR, Orange**

The content industry has realized the potential of VR360 and Disney, for example, recently announced that it will bring its most beloved characters to VR headsets<sup>8</sup>.

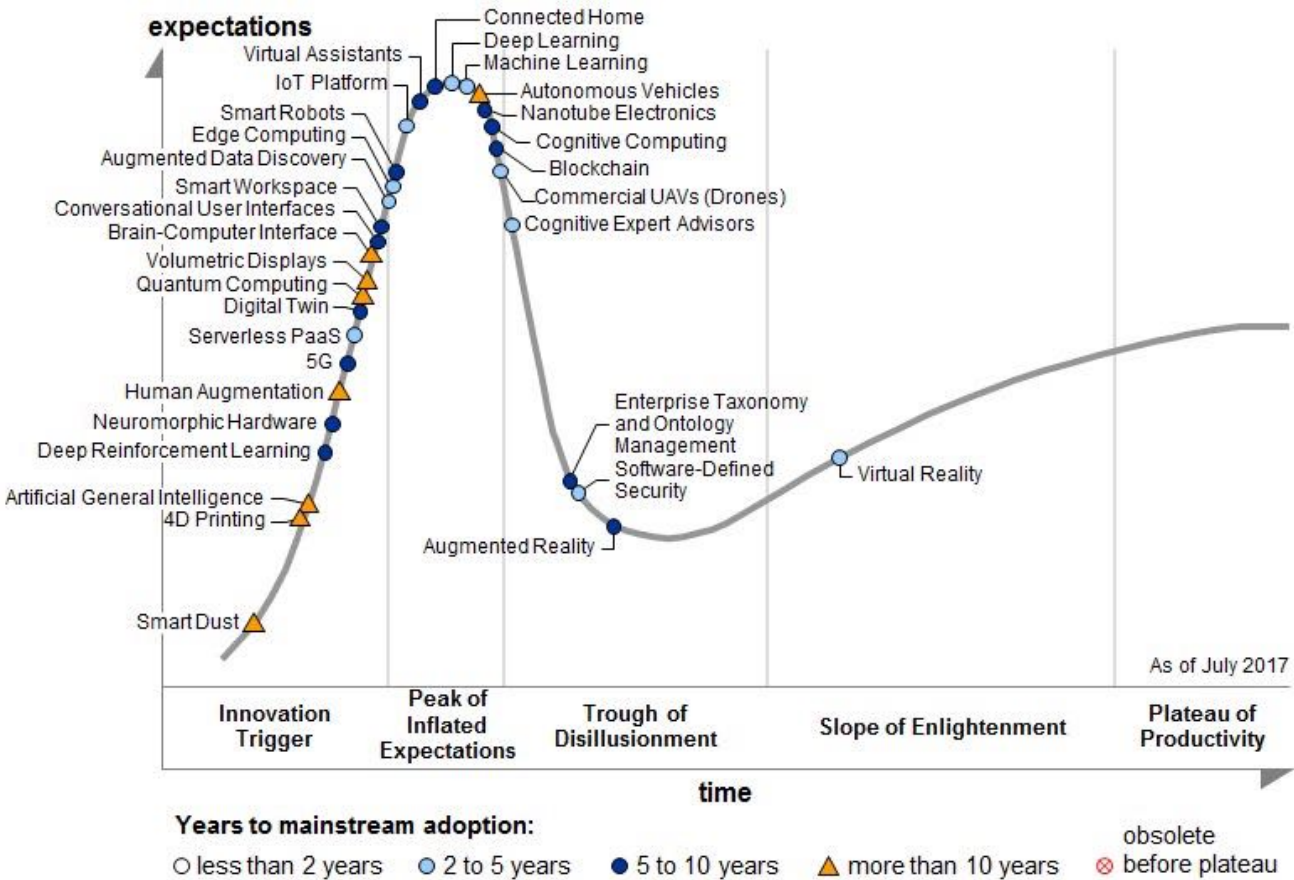


*Even before monetization is effective, VR360 will help TV operators retain broadcast contracts and premium content by remaining relevant and cutting edge. Good VR360 won't be an experience easily pirated or duplicated on a low-budget scale."*

**Alex Berriman eSports and VR Specialist at PCCW Global**

**Gartner Hype Cycle for Emerging Technologies, 2017**

Figure 3.





*So far at Sky Italia, VR360 has generally been used to promote the brand. It has been a content-driven approach, staging events or capturing 360-degree video when the opportunities arise."*

**Massimo Bertolotti, Head of Engineering and Innovation at SKY Italia**

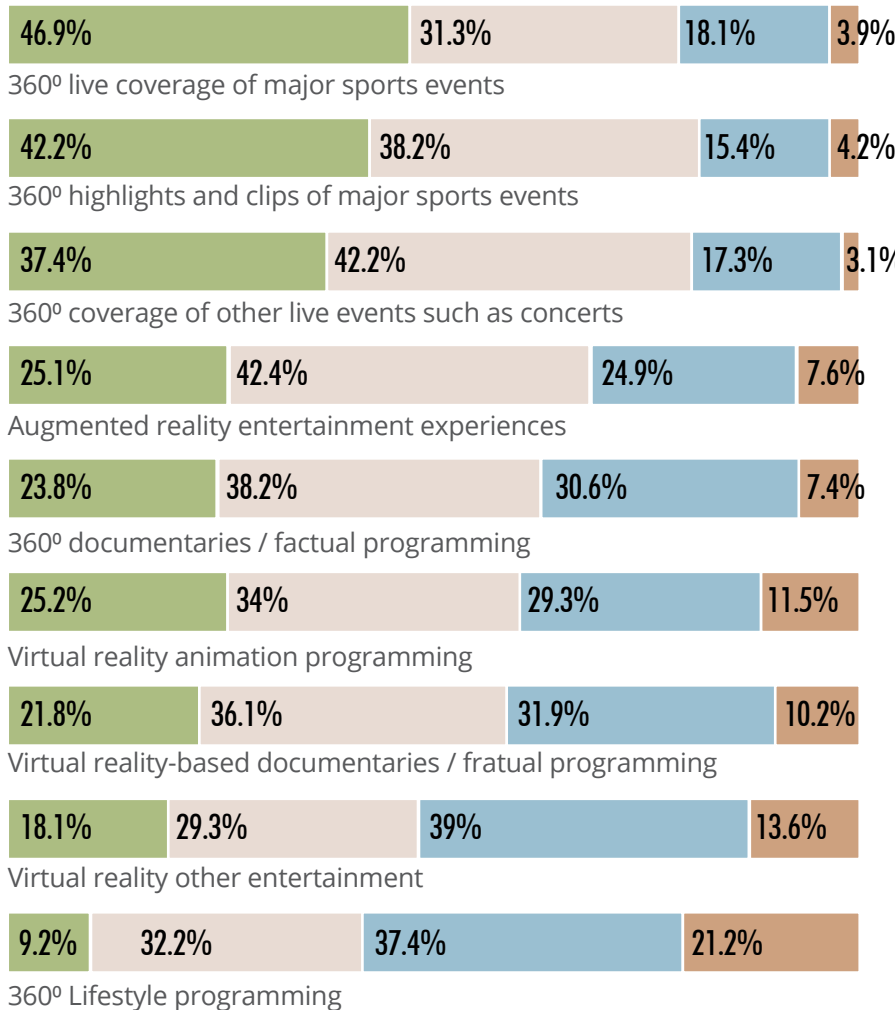
Despite consumer enthusiasm for VR, initial demand is hard to monetize. Google, for example, became the king of search well before it invented its very own ad-based business model.

VR360 will truly affect storytelling and emotions beyond the mere wow factor and that will eventually lead to monetization.



*We took our role as a storyteller very seriously, bringing the best views and pictures to our audience, allowing them to delve deeper into what they were watching."*

**Jamie Hindhaugh, COO of BT Sport on the operator's VR360 efforts with football<sup>9</sup>.**



- Very high potential
- Moderately high potential
- Moderately low potential
- Very low potential

**Figure 4.** Extract from DTVE Survey: VR potential of content genres

Operators currently charging a premium for UHD TV over HD TV are looking to VR360 as a possible complementary offering, or even to become the premium offering in the future. For others, it's about growing brand value, retaining and acquiring customers.

The more disruptive an innovation, the harder it is to see where exactly business growth will come from, but already some use cases seem promising. Table 1 (see next page) is sorted by descending priority after talking with early adopters like Sky, PCCW, BT and Orange. Engaging viewers more with the content adds to its value. People only invest time and emotion if they care. The "lean-forward" approach users take with VR360

means any relevant advertising at that time will have a much greater effect.

Think of it like Google's secret sauce that helped invent its business model once eyeballs were under control. Flashing the right personalized ad when users' minds are open and looking for results is the optimal time. Even if they don't engage (click), the message (impression) has a higher chance of sticking.

Having a state-of-the-art analytics capability in the back-end is therefore crucial. And as value increases, operators will also seek to protect this new content and its future revenue streams.

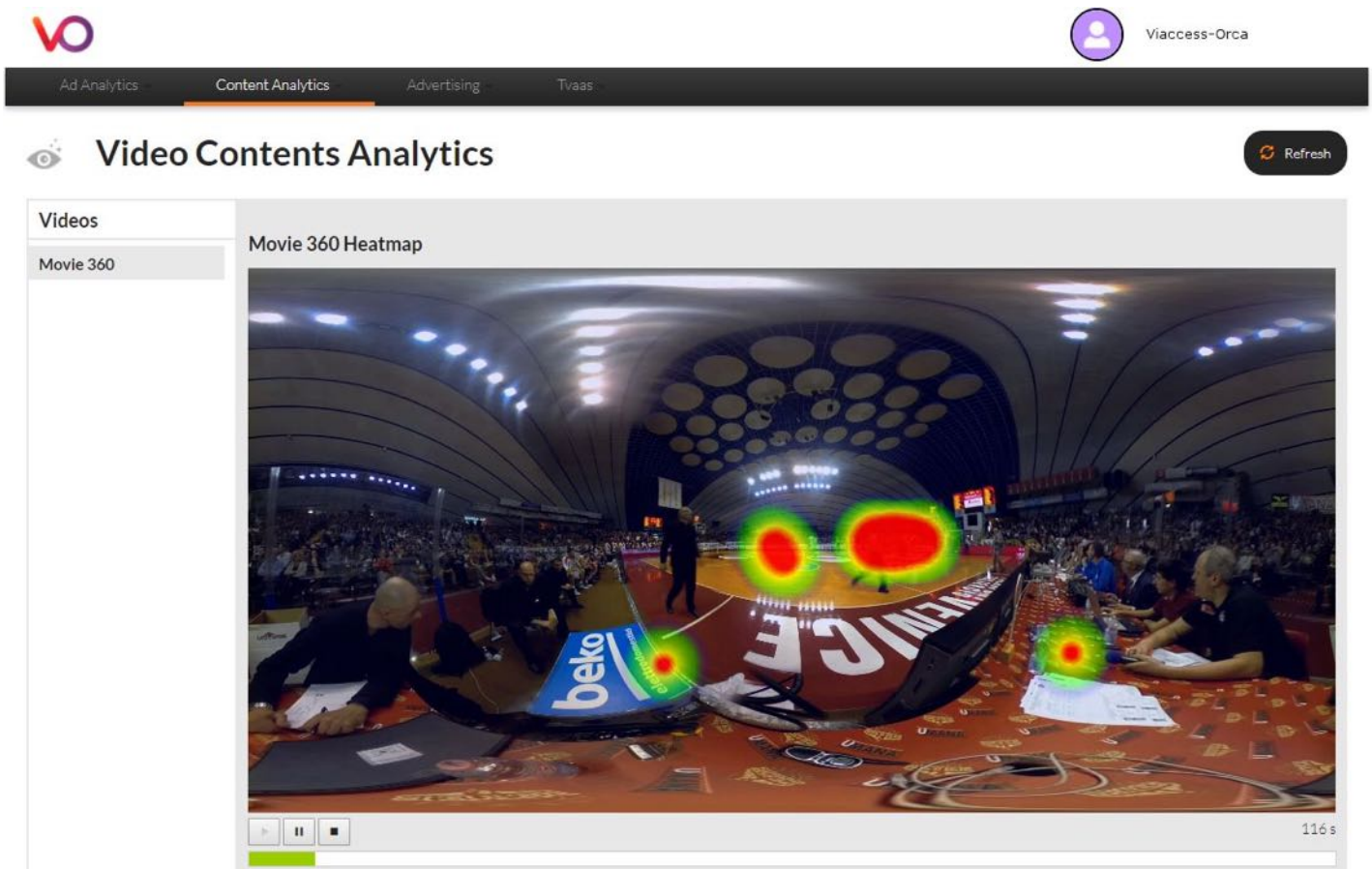


Figure 5. Heat map analysis from Viaccess-Orca's analytics back-end

## VR 360 Use Cases

Use Case	Details	Consumption mode	Why VR?
<b>Live sports</b>	Soccer, football, hockey, tennis already trialed	Addition to the TV broadcast, via the internet; unicast delivery mostly, broadcast also possible (LTE broadcast application)	Personalized view (multi-cam in unicast); interactive app and navigation is key;  immersive audio will be key differentiator vs. broadcast
<b>TV shows</b>	VR panoramic view	Addition to the TV broadcast, via the internet	Mobile consumption or optionally with HMD
<b>Concerts</b>	Panoramic filming with VR audio	Free, SVOD, or EST service	VR audio will bring a new dimension
<b>Documentary</b>	Panoramic filming of scenes: nature, natural disaster, war zones, etc.	Free, SVOD, or EST service	Panoramic filming can even be too emotionally engaging for some dramatic events
<b>Sports highlights</b>	Post produced from live capture	Bonus package delivered over the internet	Game highlights; watch action from different angle
<b>Bonus for 2D movies</b>	View from the actor  Selected scenes filmed in VR  Promotions	Add-on with movie purchase/rental  Promotion (e.g., YouTube trailer like Kong VR <sup>11</sup> )	Head-mounted devices (HMD) provide an immersive experience
<b>Short-form</b>	New genre being invented <sup>12</sup>	Free or pay service, via the internet	Like mobile video production
<b>Mesh Video/3D Gfx</b>	Mix of video and graphics, game-style, but transmitted as video	Use game technologies to deliver video and graphics in 3D	New technology
<b>News</b>	News live or post produced	Addition to the TV broadcast, via the internet	Panoramic filming is proven to be more engaging for dramatic events

**Table 1.** VR360 use cases, T. Fautier, DVB Study Mission 2016

We are still just at the beginning of the VR360 adventure and the VR use cases (see Table 1) above is already compelling. Operators in different markets may sort the table differently, and new use cases will appear regularly.

But in all use cases described, users will engage more with immersive content, which increases the potential for monetization of a premium experience.

## Gaming and VR

Existing game studios have been working with 3D graphics for decades. So, moving into VR is an easy and natural step for them to take. Even the VR luddites agree that VR is here to stay, at least in that area. As the earliest use case, it tells us something about the kind of video applications that can succeed in VR: highly engaging, interactive and social. All three attributes can be found in

the premium video experience in general, and in VR360 streaming of live events in particular.

Sam Rosen, the leading VR analyst from ABI Research, recently predicted comparative growth of the gaming market in general, with the dedicated VR industry (see Table 2).

	2017	2022	CAGR
Gaming market	\$86B	\$128B	8.5%
Dedicated VR industry	\$0.6B	\$18B	95%

**Table 2.** Growth of gaming vs. dedicated VR industries. Source ABI Research, September 2017

## More Analytics for More Privacy and Protection

Way before Amazon or Google showed us the power of big data and analytics, the TV industry has promised to exploit its potential for a truly personal experience. Finally, it seems poised to leverage analytics, but if the whole idea is to create a personal experience, then VR360 has a clear head start, as the experience is already personal.

Consumers will look for the best possible experience with VR360. Premium content is expensive so it must be monetized and protected, with data exploited for a truly personalized experience. Operators will, for example, be able to predict precisely what users watch for even more relevant ads and to recommend the right content. VR is adding to the growth in volume, velocity and variety of data<sup>10</sup>. But accessing more sensitive data requires beefed up privacy and security, especially in Europe where EU privacy laws are stringent, as confirmed by Orange.



*Security and privacy are key concerns to take VR to the next level."*

**Morgan Bouchet, Head of VR, Orange**

Consumers may well have accepted that their location is known by apps on their phone to offer better services. But are they happy with a VR app knowing exactly what or who they are watching? To strengthen privacy and gain users' trust, security must be one of the founding building blocks of a VR ecosystem.

## Operators already experimenting: Cathay Pacific/HSBC Hong Kong Sevens

Cathay Pacific/HSBC Hong Kong Sevens is the country's largest, most exciting, international sporting event. With HKT's strong presence in Hong Kong, the tournament was the perfect choice for demonstrating PCCW Global's end-to-end solution for live VR360.

The operator's challenge was the high bandwidth needed for real-time live VR streaming, with data rates 17 times those of normal HD video and much more demanding on delivery networks.

PCCW Global partnered with Ideal Systems to integrate a solution for local TV provider NowTV, where Nokia OZO cameras and Harmonic encoders were used.



*We did this in just six weeks. The project literally came together the day before the event, which we made available live with multiple cameras in UHD 3D VR360 to Hong Kong viewers."*

**Alex Berriman, eSports and VR Specialist, PCCW Global**

Three Nokia OZO cameras were strategically placed around the pitch, giving users the best angle for live immersive rugby action while also enabling them to experience the stadium atmosphere.





As a result, Rugby Sevens supporters who couldn't make it to the event could experience three days of uninterrupted UHD 360 video broadcast, with Ambisonic audio, across multiple devices, including the Zeiss, Samsung Gear VR, HTC Vive, Oculus Rift and Google Cardboard.

### MOTION TO PHOTON LATENCY

Time taken between head movement and the image displayed being updated



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# Hurdles Holding VR Back

In 2016, most analysts agreed that less than 10 million VR devices were sold. With total sales over 1 million in Q1 2017 Sony has already shipped just under half a million PlayStation VR headsets, according to Research firm IDC.

This is nice progress for such a recent device, but analysts diverge with three scenarios for VR shipments in 2020:

- UBS and DB are pessimistic at 25 million units
- Frost & Sullivan are average at 50 million units
- Ovum is most optimistic at 150 million units

Let's briefly look at the issues holding VR back, including content, consumer tech, networks, social networks and fragmentation.

## The VR360 Content Gap

The cost of adding a premium VR experience to an existing game can top \$10 million<sup>13</sup>. The computer-generated VR experiences in games don't solve all technical VR360 issues.

Unlike with music or games, video content is only consumed once, making the extra cost harder to bear. Movie theatres are a key part of the content ecosystem and today they see VR360 as bypassing them. There is

therefore understandable reticence from stakeholders in that sector.

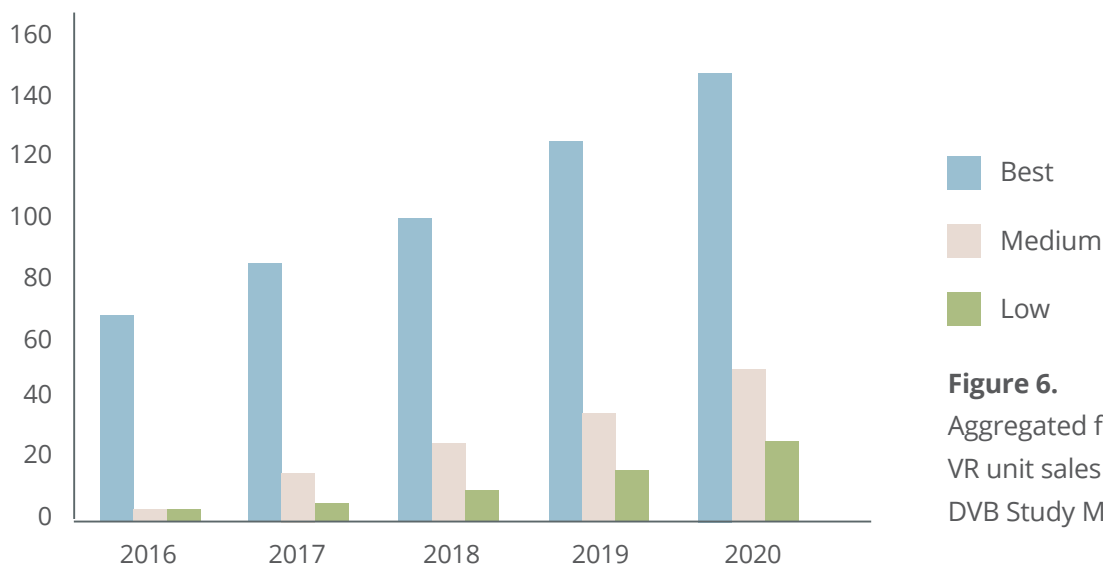
Studios are only experimenting with VR tech, with a few notable exceptions like the Martian VR Experience release by Fox in late 2016.

Content owners are also wary of making heavy investments into VR360 until they feel reassured by security solutions.

## Audio

A premium experience requires audio to be as responsive and immersive as video. Deploying immersive audio to the field has proven challenging. Operators need to either build on existing audio codecs such as AC3, that

then require other technologies for advanced audio spatialization, or look to newer codecs such as DTS:X, for example, that are not yet widely available throughout the distribution chain.



**Figure 6.** Aggregated forecast for VR unit sales (Q2 2016), DVB Study Mission 2016

## Security

The issue lies mainly with the secure data path, which doesn't exist yet on GPUs that are needed in decoding VR360.

Hardware solutions won't be pervasive for a few years, and content can always leak through HDMI connections.

## Consumer Technology Limitations

A clear limitation of premium VR360 experiences today is in the HMD specifications. Namely the low resolution and the need for tethering for the high-end devices like the HTC Vive.

Table 3 shows the currently commercialized HMDs and how they compare with the UHD experience on TVs.

With low-quality video, this must be paramount for immersive experiences to become truly believable.

High-end HMDs will need to increase resolution by several orders of magnitude from today's 1k\*1k to deliver a similar level of detail as a 4K TV set while retaining the current 100° FoV (Field of View).



*Even for local playback without streaming, some devices cannot yet handle more than 4K for the total 360 sphere."*

**Rob Koenen, President VR Industry Forum**

Pixels per degree is the most useful measure of fidelity in the VR360 context. There is only so far that one can suspend disbelief.

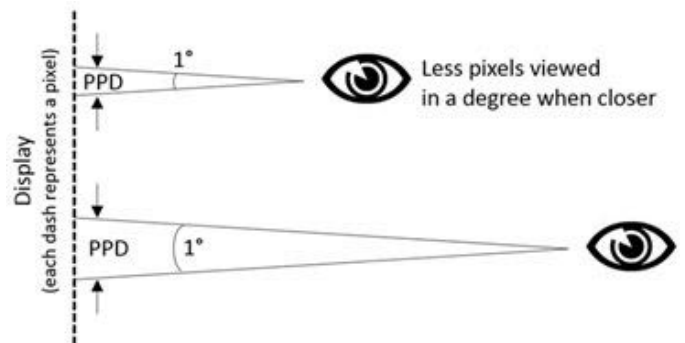


Figure 7. PPD courtesy debaffle.net

Device	Resolution	FPS	min/max Field of View Horizontal & Vertical	min/max pixels per degree
Samsung Gear	2560x1440	p60	max 96°	min: 13 H & 15 V
Oculus Rift	2160x1200	p90	67°-96° H & 66°-107° V	11-16 H & 11-18 V
HTC Vive	2160x1200	p90	76°-100° H & 77°-113°V	11-14H & 10.5-15.5V
PlayStation®VR	1920x1080	p120	max 100°	min: 9.5 H & 11 V
TV (Full HD)	1920x1080	p30	avg: 45 H & 25 V	43 H & 43 V
TV (4K)	3840x2160	p120	avg: 45 H & 25 V	86 H & 86 V

Table 3. Commercialized HMDs vs UHD Experience on TVs



*The painful compromise between resolution and bitrate is today's most urgent bottleneck for improving the video 360 experience."*

**Thierry Fautier, VP Video Strategy, Harmonic**

In experimentation with football, Sky Italia has seen issues arise when the action is too fast for current HMDs and the experience of interactivity is lost. Feedback is, however, consistently positive for content where users tend to move their head more slowly.

BT's Head of Interactive TV Research told us that early trials of live VR sports broadcast saw issues with smartphones overheating and running out of power, meaning most viewers were unable to watch a full 90-minute VR football match.

Even though vast improvements to the user experience (UX) are happening all the time, this remains a nascent industry, and in many ways we're still wandering around in the dark. We don't, for example, know if a wider FoV will improve the experience more than greater base resolution.

## ■ Networks and Streaming

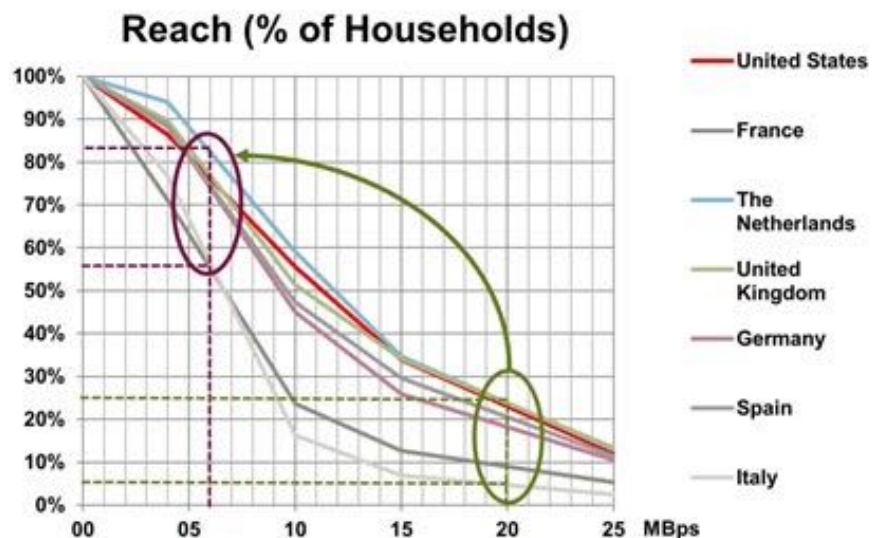


*Streaming the entire 360° panorama requires significant bandwidth and provides mediocre quality."*

**Rob Koenen, VR Industry Forum President**

With today's "brute force" approach, every single pixel of a 360-degree video stitched into a 3840x1920 stream is transmitted to the HMD that only ever displays up to a maximum of 1280x960 pixels to each eye. Usually it's significantly less because of the barrel shape that the image needs to take on.

So, streaming this 4K video only delivers an HD image at any one time, but still requires a bandwidth of over 20 Mbps, which, as Figure 8. shows, severely limits service reach in all but the most developed markets.



**Figure 8.** Broadband penetration of some key markets.

Source: Akamai's State of the Internet, Q3 2016 report

# Latency and Motion Sickness

Motion-to-photon latency, at least for the base layer, must be kept below 15-20ms. This would disqualify even the fastest video stream channel change technologies, which are considered fast at anything under 500ms.



*Using an interactive immersive viewing device brings a critical constraint on what we call motion-to-photon latency. Motion sickness is immediate when video freezes, as anyone who has experienced a software crash while playing a VR game will confirm.”*

**Rob Koenen, VR Industry Forum President**

Refresh rate must always remain high enough to prevent flicker, which would be even more unpleasant in an HMD than on a TV.

The current generation of video acquisition systems is

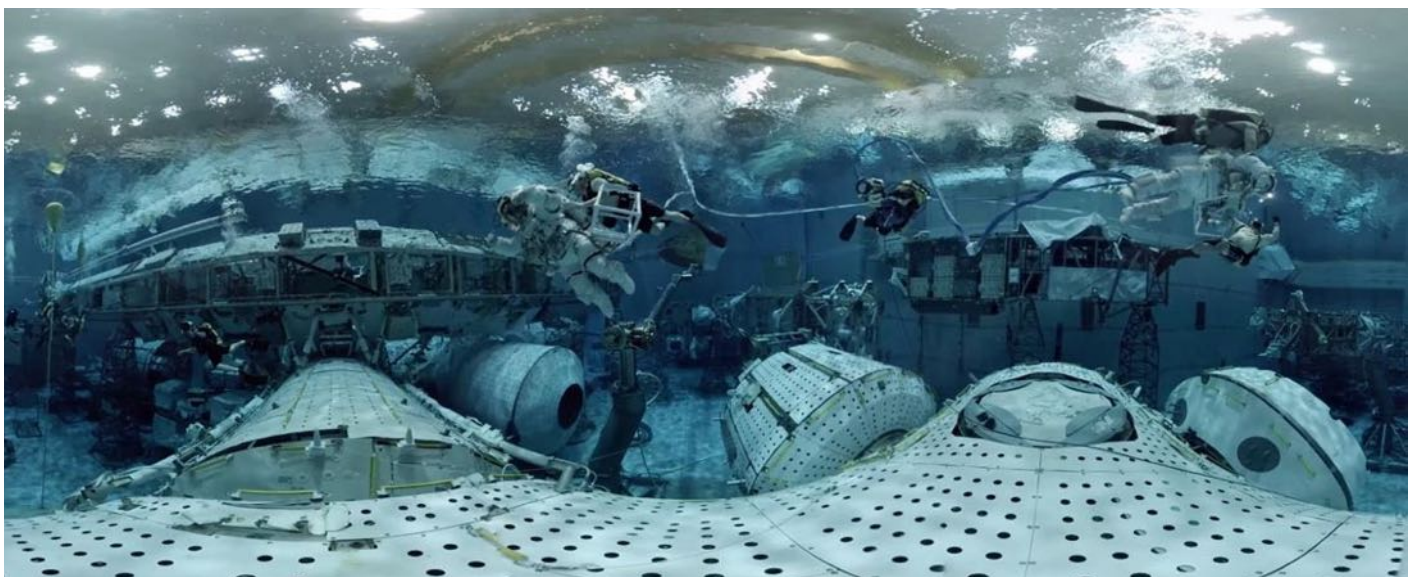
usually at 60fps. UHD is gaining ground, and industry pundits expect it to double up to 100fps or 120fps as it progresses to Phase 2 in 2018 and beyond.

Today’s high-end consumer-grade HMDs support 90fps, which is one reason why they still need to be tethered to a device with a powerful GPU.

Motion-to-photon latency must be below 20ms for users to perceive immediate feedback from their head movements.

Vection, the sensation of movement caused by visual effects, can also cause motion sickness. This happens when fast-motion objects in the near field create the illusion that the user is moving and the world is stationary (a bit like when a nearby train moves and one thinks that one’s own stationary train has moved in the opposite direction).

Exposure to VR360 over long periods can also cause issues. Recent experiments using existing technology showed that all users are comfortable with up to at least 20 minutes of consecutive viewing. Active users of the Oculus Rift headset spend 25 minutes a day on their device<sup>14</sup>.



NASA VR360 is a 360-degree immersive virtual reality viewing experience, featuring exclusive astronaut training footage from NASA’s Neutral Buoyancy Laboratory in Houston, Texas. The stunning NASA VR/360 video was produced by Harmonic.



**Figure 9.** Virtual Arena application, integrating social links. Source: VO

## ■ Human (social) networks

The point of VR is to create a realistic sense of being there. But VR/AR technologies aren't yet ready to create life-like avatars. Once you have a headset on, another person's presence in the same virtual space (or your own presence) is only possible today with a simplistic avatar. But this will change soon, as many companies, including Facebook, are working on this.

Despite all the excitement it generated, AltSpace VR almost closed in the summer of 2017, illustrating that combining social media and VR is taking longer than hoped.

Integrating social media into the VR360 experience is essential to break the isolation users can otherwise feel when wearing a headset. The screenshot above shows an example from VO's Virtual Arena application.



## ■ Fragmentation

Consumers don't know which equipment to buy while content producers hesitate over which ecosystem to support. Until some interoperability can be guaranteed, this confusion will continue to slow down the market and make the use of an independent 360 player that manages heterogeneity, more future-proof than using a native player. Ecosystems today include several types of tethered headsets:

- high-end gaming-centric HTC Vive with Valve
- mid-range gaming system Sony PS,
- the more social-focused Oculus from Facebook
- devices from Microsoft.

But opponents of these tethered environments are quick to quip that you can't truly lose yourself in VR if you keep getting tangled up. Most analysts agree that the future lies with wireless solutions allowing for freer movement and a greater sense of immersion. Untethered environments include:

- Samsung Gear for Galaxy phones
- Google Cardboard or newer Daydream

Apple has announced support for untethered AR applications. But when world-dominating Silicon Valley-based giants intervene to reduce fragmentation, the results can be unpredictable. The Global VR Association (GVRA) for example, is an association where the likes of Facebook and Google get together to promote the mass adoption of VR.

From a VR360 perspective, where wide distribution is key and the experience is more video-centric than interactive, Samsung Gear and Google's Cardboard/Daydream are the main targets today.

## ■ Live VR Workflow

The operators that created live VR360 feeds for sporting events have had to build their own workflows. Concepts such as tiling, discussed below, will also affect workflows.



*Providing a separate commentary was probably the most difficult part. I asked the question, 'how will the commentator know what is going on?' because you need to be able to see the whole 360 degrees of content. So, again, we developed a tool, that looks like an app on a smartphone, with a big touchscreen monitor to enable the commentator to look around and experience the environment himself."*

**Andy Beale, BT Sport Chief Engineer<sup>15</sup>**



# Crossing the Chasm to the VR360 Promise

VR360 quality is paramount to deliver “premium video experiences.” Below are the video workflow elements that impact its QoE.

**Capture quality** is affected by the type of camera, focal depth, resolution and light.

**Sensitivity** is impacted by the type of rig relied upon. A multi-HD rig stitched into Ultra HD (3840x2160 @30 or 60fps) is usually used for VR360. For high-quality 8K resolution (7680x4320@60fps), a multi-UHD rig is used.

**Stitching** takes non-aligned views from different cameras, corrects aberrations and provides a single 180-degree or 360-degree view. Stitching in real time for live content is still state-of-the-art for both 4K and 8K output resolution. Fish-eye cameras can omit the stitching process. However, their lower resolution and frame rate prevent their use for delivering premium experiences for now.

There are multiple projections for **mapping** a sphere to flat image, the most popular being equirectangular and cubic projection, the latter providing a more efficient compression. Their impact on QoE is mostly on distortion and can affect bitrates. Initial deployments used equirectangular mapping. Although this is a critical part of the technology, it has little business impact for operators.

As HMD resolution only allows for the display of part of this subset, we can capture a larger resolution

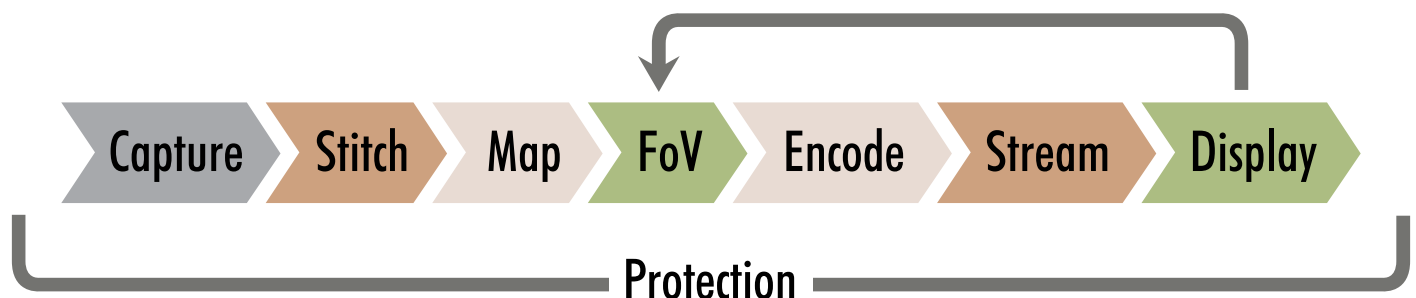
than the HMD FoV and only transmit the FoV. Most recent HMD (2540x1440) allow us to capture a larger view (6000x3500), about six times more pixels than transmitted.

HEVC is the codec of choice for **encoding** because of its native tiling support. For 4K and 8K resolutions, this is also the most efficient and deployed codec in mobile devices.

**Adaptive streaming** delivers the best possible resolution, even as available bandwidth decreases below the ideal level. If the resolution drops too low, user experience can become unacceptable. If a low-latency feedback loop is available, this is where viewport-adaptive techniques can save the day. Only the viewed part of the picture is transmitted. What would have required 20Mbps with a brute force approach of sending the complete 360 degrees of video, can now be achieved in as little as 4Mbps. Ready-to-run apps like the Virtual Arena from VO can already deliver this for sports and live events and increase monetization opportunities. A video player such as the VO Player can be integrated to orchestrate tiled video, spatial audio and social content.

For premium VR360 to go mainstream in the short-term, we must improve the iterative (green) part of this workflow.

## VR360 Processing Pipeline



A brute force approach, sending the whole 360 degrees of video to the end device, means that 80 percent of pixels sent are never viewed. The bandwidth vs. resolution trade-off cannot be found to deliver a good enough QoE at a reasonable cost.

Viewport-adaptive streaming schemes are a way to achieve this and for VR360, tiled VR streaming is a method where the overall latency perceived by the end-user can be kept below 20ms with the help of a CDN.

## Tiling in VR360

For Tiled Streaming, the full VR panorama is first cut into rectangular tiles that are independently decodable. HEVC is used both because of its native support for “Motion Constrained Tile Sets”<sup>16</sup>— ensuring a future-proof, standards-based approach — and because it offers the industry’s best support for resolutions of 4K and above. A CDN then distributes tiled, encoded and packaged content. Tiling only needs those tiles that are in the FoV to be streamed. With current headsets only about 15 percent of the entire panorama is displayed in the HMD as shown in Table 4. Determining which individual tiles are in view and retrieving them from the CDN is the software player’s role.

For a premium VR360 experience to be consistent with the motion users should feel and to avoid motion sickness, we need low latency.

The viewport must be updated to reflect the new FoV within 20ms of users moving their head. That is why a

low-resolution background layer is always present so that wherever the user looks, at least that lower quality video is present, and motion-to-photon latency is as low as in a brute force approach.

The human brain creates a sensation of continuity with the vestibulo-ocular reflex. This keeps the eyes focused on the same point for a short while after the head has moved, before following the head to the center of the new viewport.

When bitrate is not constrained, pushing more tiles than are displayed through the system will reduce “motion-to-high-resolution latency.” So, in the event of limited head/eye motion, adjacent tiles may already be available to the HMD.

In some cases, such as with 8K panoramas and limited decoding capability, an intermediary setup can involve pre-fetching adjacent tiles without decoding them in advance.

Tiledmedia’s research<sup>18</sup> shows that the extra delay provided by the vestibulo-ocular reflex means that the tiling system must switch to the high-resolution tiles only when the eyes are realigned and have reaccommodated, i.e., within one to two frames. In this case, users do not perceive any noticeable drop in video quality.

### BASE-LAYER

(or fall-back layer) Low-res video stream always available to be displayed while waiting to receive high-res video

Device	Type	Resolution	Max frame Rate	Supported Codecs
Samsung Gear VR + Galaxy S6/S7/S8	Untethered	2560x1440	60	HEVC
Google Daydream	Untethered	2560x1440	60	HEVC
Apple iPhone + HMD <sup>17</sup>	Untethered	1920x1080	60	AVC/HEVC
Oculus Rift	Tethered	2160x1200	90	AVC, HEVC
HTC Vive	Tethered	2160x1200	90	AVC, HEVC

**Table 4.** HMD specs for VR360



**Figure 10.** Viewpoint dependent tiling (Blue Man Group demo at NAB Show 2017)

## ■ Breaking down latency

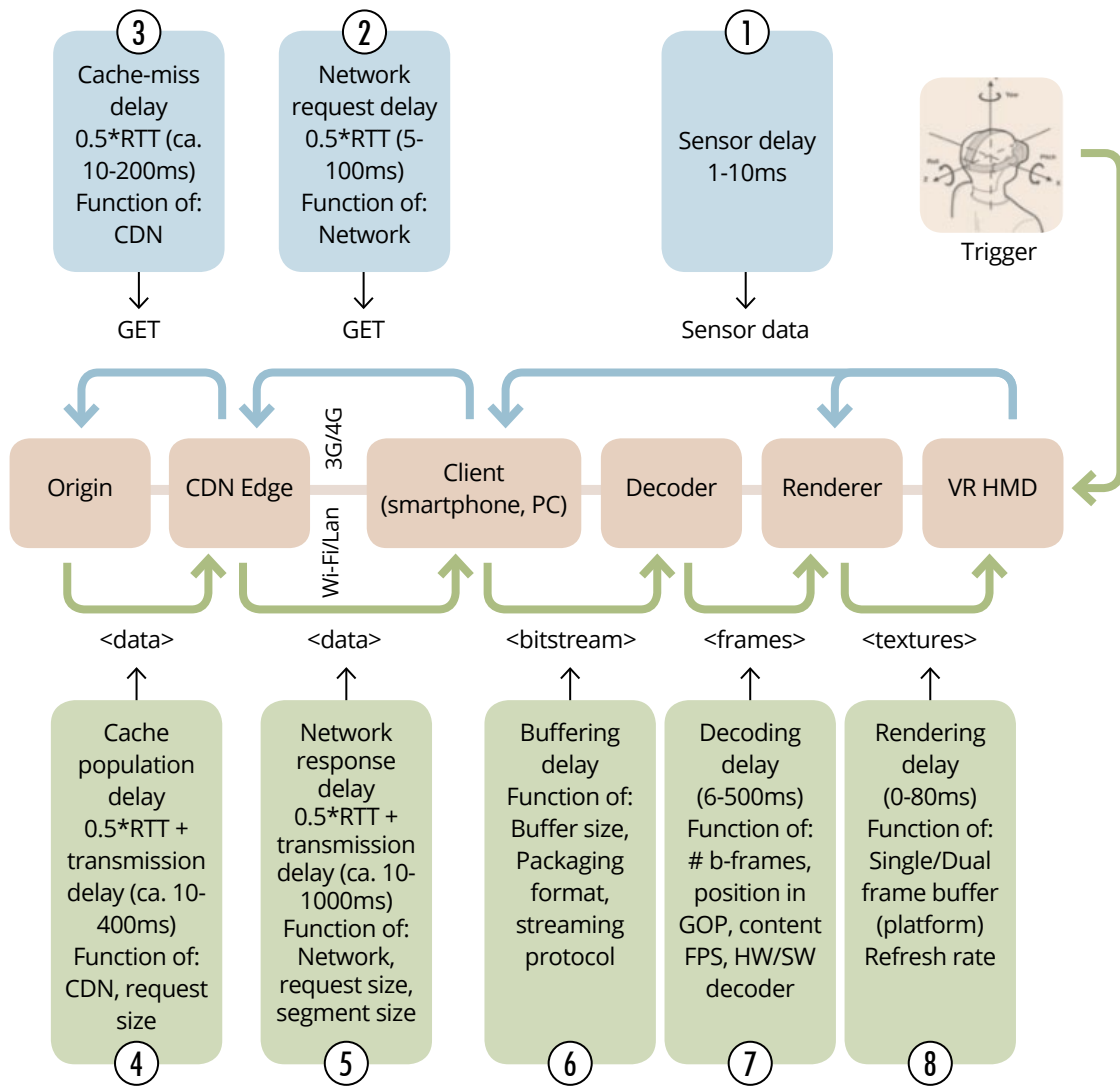
Latency has long been a stumbling block for delivering services over the internet. Tiling will complement other initiatives, bringing a breakthrough in terms of reducing VR360 latency to acceptable levels.

In their IBC 2017 paper<sup>18</sup> Tiled Media and Akamai identify over 10 subcomponents of motion-to-photon latency. Because latency is so critical to VR360, we present those to you here:

- 1 **Sensor latency** marks the time from head movement to the point that the sensor signal becomes available to the VR system.
- 2 **Network request delay** is the time for the client software to request a new stream or tile from the CDN.
- 3 **Origin-to-edge latency**, the most variable performance factor, is caused by cache misses in the CDN and can be eliminated by pushing the entire 360 sphere to the edge.
- 4 **Access network** transport from edge to customer premises is usually the greatest latency factor.
- 5 **Home networks** introduce latency, especially with Wi-Fi.
- 6 **Buffering** in the client device before playback strongly impacts user-perceived latency.
- 7 **Decoding delay** is determined by random access latency and the design of the decoder pipeline.
- 8 **Rendering delay** is also incurred by the HMD and is very influential on motion-to-photon latency.

**End-to-end latency is akin to motion-to-high-res latency**, which is the end-to-end time from head motion to high-res content being updated in the HMD. It's critical for a premium experience.

Note that **motion-to-low-res latency** is the same as motion-to-photon latency for brute force approaches where the whole 360-degree video is sent to the HMD at all times. With tiling, it is the hardware-dependent time required to display video in low-res from the base layer, which is always present.



**Figure 11.** Applying latency model to client-controlled tile-based streaming. Source: Tiledmedia



# Integrating Tiling Throughout the Complete Delivery Chain

The video player determines which tiles to pre-fetch. Even though all the key parts of tiling are becoming standards-based, software implementation within a video player is particularly critical to the quality of the final end-user experience, as the player orchestrates the whole delivery chain, even if decoding uses hardware components.

Mode	Codec	Mode/resolution	ABR	Target
Broadcast production	AVC	Single bitrate 1080p30	No (RTMP)	YouTube, Facebook
	AVC	Multi-bitrate: 1080p30 (HD) 720p30 (HD) 576p30 (SD) 240p30 (QVGA)	HLS	iOS legacy device Web browser Generic HMD system
Unicast production	AVC	Multi-bitrate: 1080p30 (HD) 720p30 (HD) 576p30 (SD) 240p30 (QVGA)	HLS	iOS legacy device (with/without HMD) Web browser Generic HMD
	HEVC	Multi-bitrate: 2160p30 1080p30* 720p30* 576p30*	DASH HLS*	Gear VR iOS HEVC devices only*

**Table 5.** Example from a Harmonic live deployment offering VR360

To further expand upon this description of real-world parameters, the following table shows the encoding parameters used with tiling.

	Horizontal Resolution	Vertical Resolution
Source Resolution	8192	4096
Field of View Resolution	2048	2048
Transmitted Resolution	2048 – 2560	2048 – 2560
Display	~2400 (~1200/eye)	~1100
Transmitted Bitrate	~15 Mbps	
Target Delay	Base HMD delay (base layer) ~40ms (switch to hi-res)	

**Table 6.** Resolution used for tiling in 2017

In successful past deployments, Harmonic and VO have developed several end-to-end ecosystems that fully support tiling including the following one:



Tiled VR360 was demonstrated to much acclaim at the NAB 2017 show during the Blue Man Group demo<sup>19</sup> (see figure 10 on page 23).

## VR is Sounding Better and Better

3D audio is bringing more accurate and interactive sound positioning related to head tracking, which will further enhance immersion.

The three main approaches today are:

- Multichannel audio, which requires no processing power, but relies on the sound being configured for a specific speaker setup; this does not work well with all configurations.
- Object-based audio, which is flexible, but computationally intensive as the sound field is adapted to whatever setup a user has. Commercial formats, such as Dolby Atmos or DTS:X, use this approach.
- First Order Ambisonic (FOA) was demonstrated in the Blue Man Group demo at the NAB 2017 show, but High Order Ambisonic (HOA) is the favored solution for the future.



*HOA is available in royalty-free implementations. It can use simple stereo feedback with cheap headphones, but most importantly HOA doesn't require intensive computation at the client-side and so is "head tracking friendly," as rotating the sound field is a relatively simple operation orchestrated by our client software."*

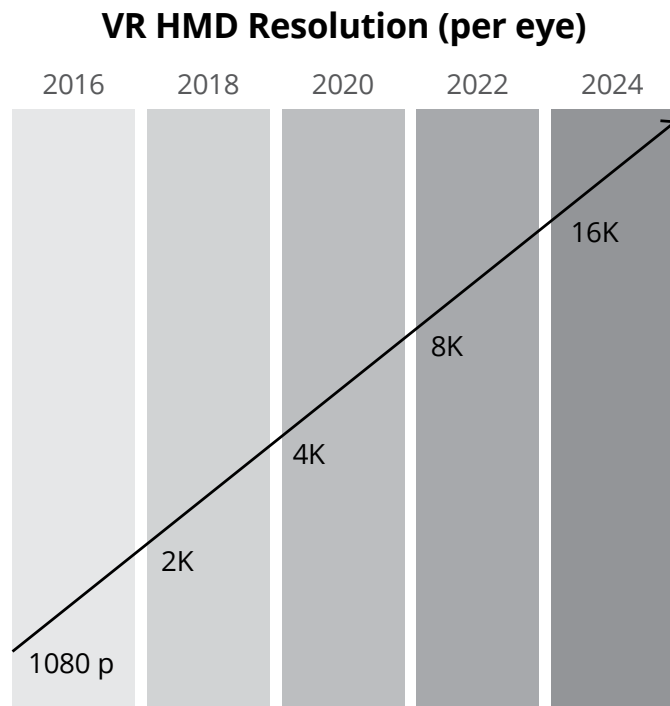
**Kévin le Jannic, Emerging Business Leader at Viaccess-Orca**

As content markets mature, operators will look to better audio as an actionable way to differentiate as pointed out by DTS<sup>20</sup>.

## Devices Twice as Good Every 18 Months

Just as in the early days of computing, technology is improving, getting smaller, more powerful and battery efficient all the time. Even if Moore's Law is less visible in CPU improvements, HMDs with well over 90 degrees of FoV and native resolutions per eye up to 4K are only a few years away.

Tethering of high-end HMDs will probably soon be a thing of the past. In the meantime, there are already devices that can support tiling. HEVC devices, some which will be able to support 8K, include Gear VR (Galaxy S7 and beyond), HEVC enabled tablets (both Apple and Android) and some STBs that can be upgraded for 4K tiling.



**Figure 12.** Mainstream VR headset resolutions. Source: ABI June 2017

## Securing Tiled Content Streams

Regular pay TV protects premium content by keeping it in a trusted environment. One issue for VR360 is that video within the FoV needs to be processed by a GPU and so be unscrambled outside the secure environment. This makes the 18 percent of the content stream available outside the secured path most prone to content piracy. At the same, the significantly higher overall video resolution constitutes a sufficient incentive for pirates to imagine more sophisticated attacks (e.g., by collusion).

Security vendors such as Viaccess-Orca are developing content protection solutions adapted to the new threat models resulting from VR360 environments.



*To unleash VR360 content creativity, service providers need to compensate for increased production costs. The availability of monetization enablers, in particular content protection solutions adapted to this new environment, will be key."*

**Alain Nochimowski, Executive VP Innovation, Viaccess-Orca.**

## ■ Content is Virtually Here

The incredible hype surrounding VR in recent years makes us forget that not just bleeding-edge development, but also academic research on immersive experiences has been progressing for many decades<sup>21</sup>. As the technology is finally maturing storytellers can lean on some very deep expertise. The new rules of content creation are being

invented as we accompany the user from spectator to participant.

The shelf life of truly interactive content will be extended. Users or viewers can indeed experience any piece of content in different ways, then again and again in new ways with improved devices as they become available.

## ■ Standardizing the Way Forward

Standardization is critical to the success of VR360. Some key suppliers are helping to create de-facto standards such as Unity, the software platform for creating 3D environments that also uses the royalty-free OpenXR™ framework. The WebVR protocol is also gaining a lot of traction for incorporating VR onto websites.

(HEVC) and protocols (MPEG-DASH). The next-generation MPEG VR framework will define the audio, video and graphics layers based on new codecs that will extend today's 3 degrees of freedom to 6, so users can not only look in different directions, but also move around inside the video.



*The market will consolidate into just a few V360 streaming platforms. We expect standards-based initiatives like tiling to ensure a fair level of interoperability."*

**Sam Rosen, Vice President,  
Consumer at ABI Research**

Key video Standards Developing Organizations (SDOs) like DVB are starting to actively engage on VR360 to ensure future interoperability.

MPEG has created the Omnidirectional Media Format (OMAF), which defines all the parameters to deliver a high-quality VR360 experience using existing codecs

A next-generation system might be a hybrid between tiling, on-demand transcoding and polygon mapping. Harmonic and Viaccess-Orca recognize the importance of the industry coalescing around the right standards and are both active and founding members of the VR Industry

Forum (<http://www.vr-if.org/>), where a complete end-to-end ecosystem that includes production, encoding, delivery, decoding, display and interactivity are in discussion.

### **VESTIBULO-OCULAR REFLEX**

Tiny delay before the human eye follows, after the head has turned

# Afterthought

## ■ Untapped Potential

Content companies see the opportunity for putting value back into content if it can be delivered to enough people at a manageable cost. The difficulty with delivering VR360 has been addressed with tiling, and the technology is now ready for user trials and that is expected to become a market reality in 2018.

But even today's most premium VR experience is very basic, compared with what lies ahead. In the longer term, VR360 video itself will get a quantum leap in the quality of experience with 6 degrees of freedom. Users will be able not only to look in different directions within the video, but also move around within it.



*We're now looking at ways to deliver higher resolution 360-degree video beyond 4K, which should enable us to offer additional features such as zoom."*

**Andy Gower, Head of  
Interactive TV Research, BT**

If the relative pace at which VR, AR and VR360 will become mainstream is still under debate, Hollywood has long-acknowledged that the mixing of computer-generated graphics and video is becoming central, as shown in box-office hits like Ridley Scott's "The Martian."

VR will enable new domains. In July 2017, Wired explored a great new world of VR advertising for example, where you walk into a fully personalized branded experience.



*VR360 video will soon have more interactivity with multiple endings, overlay graphics on footage, and then the possibility to navigate within the video itself."*

**Sam Rosen Vice President,  
Consumer at ABI Research**

## ■ Investing in VR360 Now Will Bring Returns in All Cases

V360 content changes the viewer's role from passive spectator to active participant. TV operators all over the world are struggling with how to deal with lean-forward Millennials who refuse their parent's couch-potato attitude. Although it may seem counterintuitive, an intense time-limited immersive session with a head-set may not isolate a teenager any more than by being constantly connected on multiple devices at once, as many are today.

Even if the premise of this eBook, that VR will be increasingly important is wrong, the change in the consumer paradigm is already happening. We believe VR360 is the beginning of something big and that operators that have participated in the V360 adventure will be better equipped to respond to future generations of active viewers.

# VO and Harmonic: An end-to-end solution

This pre-integrated solution is compatible with industry standards and is field-proven. Harmonic provides both live and file-based encoding for legacy and tiling approaches, encryption, and an origin server to also deliver on-demand services. Viaccess-Orca provides a 360-degree secure video player, content protection, a VR360 analytics and advertising platform as well as multi-device applications.



*Thanks to technology partners like Harmonic, NASA has been at the forefront of delivering amazing video experiences, including virtual reality."*

**Fred Brown, Executive Producer of NASA TV**

A best-of-breed solution combines the most cost-effective technologies on the market, with the flexibility to be

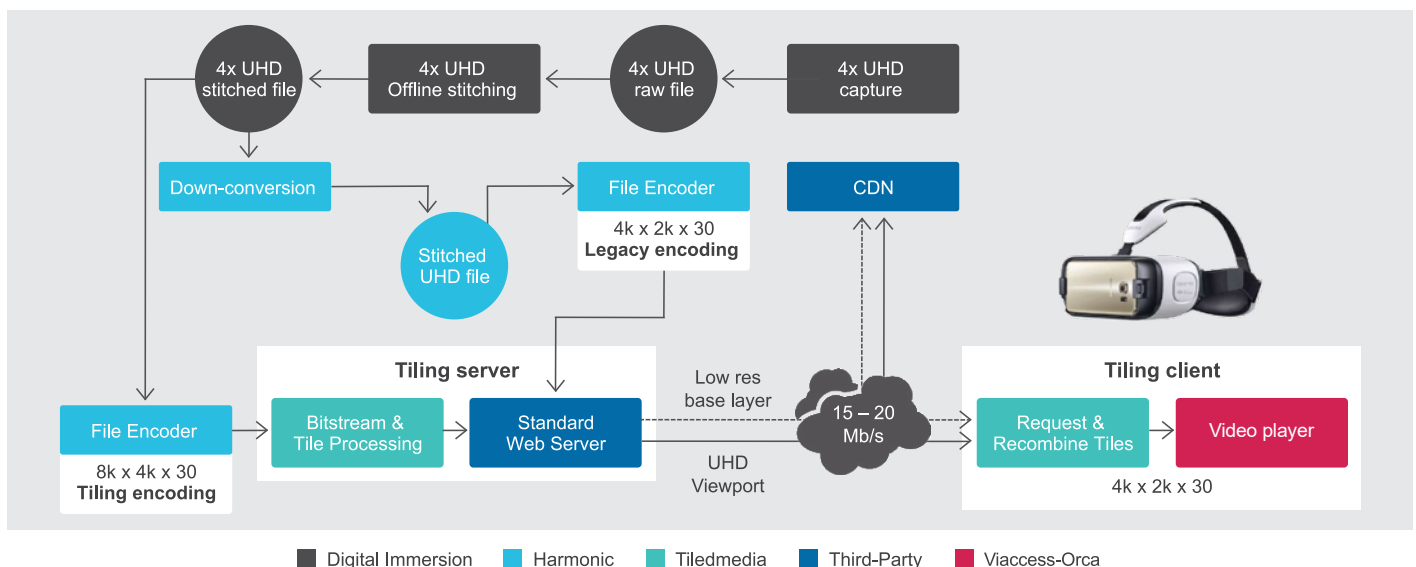
able to plug in or out any component as deployment or market constraints evolve.

- Viaccess-Orca's core business is to provide the best immersion through the best audio, video and data-driven personalization. To learn more, visit: [www.viaccess-orca.com](http://www.viaccess-orca.com)
- Harmonic compression systems are part of a comprehensive solution for the preparation and delivery of real-time and on-demand VR video. To learn more, visit: <https://www.harmonicinc.com/solutions/vr-video-processing/>

## FOVEATED RENDERING

Future technology reducing quality in the peripheral vision (outside of the zone gazed by the fovea). Requires eye-tracking.

### End-to-End Solution



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