IMMERSIVE MEDIA BUSINESS BRIEF

Intel Corporation

Augmented and Virtual Reality for Service Providers

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1.0 Executive Summary

Augmented reality (AR) and virtual reality (VR) have become cornerstone examples of how human beings will interact with the world of tomorrow. The broad application of these technologies has attracted a large number of innovators who are exploring its full potential, all while they bring new products, services, and business models into the marketplace.

The revenue opportunity remains strong, estimated to exceed $45 billion (USD) in headset hardware sales by the year 2021.[1] Software will be similarly significant, expected to exceed $35 billion, spanning both consumer and enterprise use cases, by 2025.[2] For content distribution, the cloud has become increasingly important, providing platform and infrastructure services (e.g., cloud rendering) that can address the scalability limitations with on premise AR/VR experiences. Cisco* forecasts video streaming workloads within the data center will maintain a 32 percent compound annual growth rate (CAGR) through 2020, a majority running in a public cloud.[3] With public cloud spending estimates of $162 billion by 2020, the opportunity is significant.[4]

Moving the technology beyond enthusiast use will require overcoming a number of adoption impediments such as consumption device complexity, lack of compelling content, high end-device cost, and network impediments. For service providers, addressing the bandwidth and latency deficiencies associated with the delivery of immersive media will be increasingly important for content passing over their network to ensure a sustained, high-quality service level and end-user experience. Approaches to overcoming these performance issues will most likely be impacted by pending changes by the Federal Communications Commission (FCC) that dismantle net neutrality in the USA; the implication for the delivery of AR/VR content and its consumption by end users is to be determined.

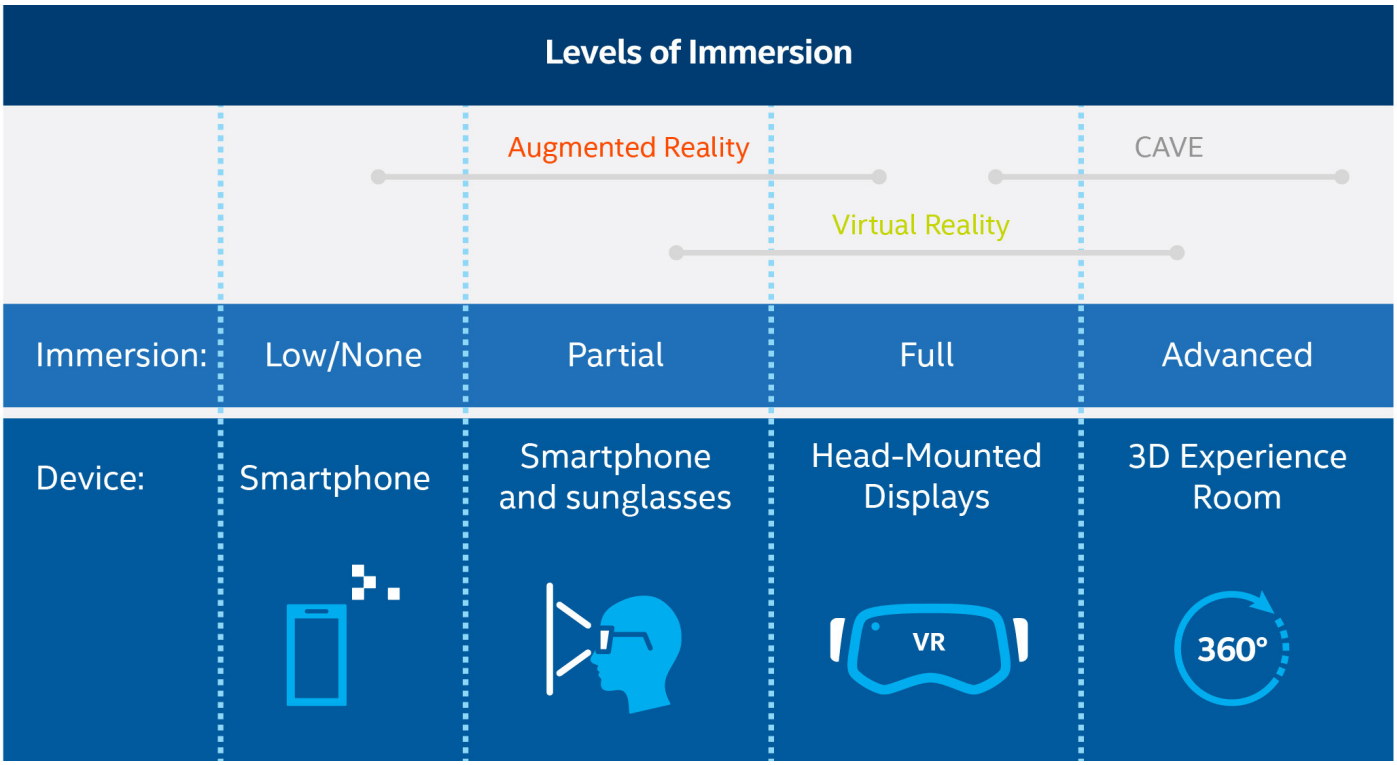
Both AR and VR technologies are similar to each other, with slight differences in application approaches and use cases. This paper is intended to help service providers understand the basics of AR and VR technologies, the industry, and market potential. Special emphasis is placed on network challenges and where service providers and the ecosystem are trending with regards to overcoming these challenges. This paper also reviews Intel's role and future plans.

Table of Contents

2.0 Introduction

As new use cases for AR and VR are introduced to the market, service providers will need to address bandwidth limitations, reduce end-to-end network latency, and improve overall quality of service for streaming media services. These challenges not only impact the consumer's AR/VR experience today, but remain an impediment to delivering more immersive experiences in real time going forward.

Figure 1 from a recent Gartner report shows the variety of immersive device types and capabilities that deliver emerging user experiences. The devices and environments include smartphones, head-mounted displays, augmented reality smartglasses, and a dedicated 3D experience rooms (cave automatic virtual environments (CAVE)).”[5]



Source: Gartner, Top 10 Strategic Technology Trends for 2017: Virtual Reality and Augmented Reality, March 2017

Figure 1. Immersive User Experiences in Virtual Reality and Augmented Reality Cover a Wide Variety of Devices, Systems, and Capabilities[5]

With the expectation that AR and VR will become more ubiquitous within the next three to five years, end users will want to have options for higher quality and faster response when consuming this media type, as in a 3D Experience Room in the home.

Although immersive AR/VR experiences will place significant demands on networks, they also create an unparalleled opportunity for service providers to innovate and launch new business models.

Most analysts are bullish on AR/VR revenue and device estimates. In a recent report, IDC predicts shipments of AR/VR hardware will exceed 80 billion units by 2021, up significantly from the 9.4 billion units that were estimated to be sold in the same period. Revenues are equally compelling, topping over $45 billion for AR/VR headset hardware sales in 2021.[6]

In addition to overcoming networking challenges (both bandwidth and latency), the catalysts necessary to increase the technology adoption rate will also require evolving the consumption device, reducing its current price points, and growth of compelling content. Many in the industry remain focused on delivering a better, more attractive end-user experience in order to move the technology from being of interest to only enthusiasts to bringing it into the mainstream of media consumption.

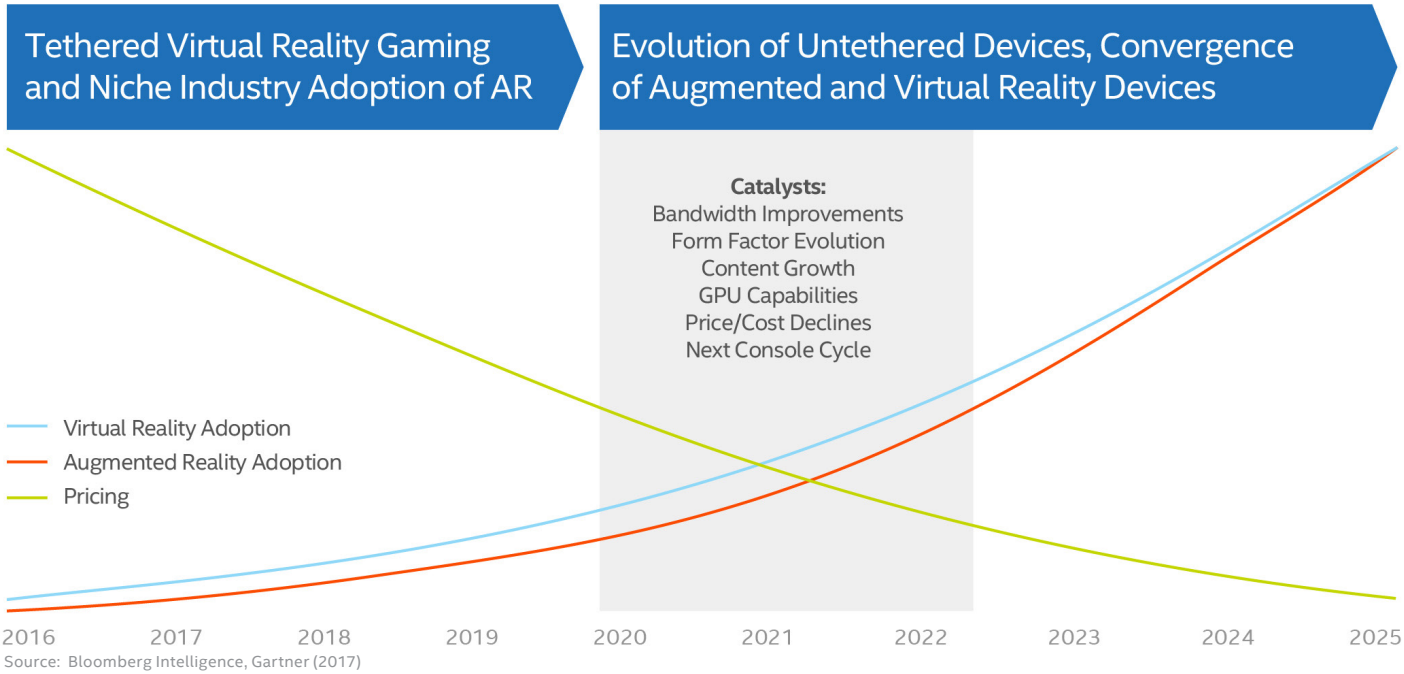


Figure 2. Virtual and Augmented Reality Adoption Rate Curves[7]

For service providers, addressing the bandwidth and latency challenges associated with an end-to-end (E2E) AR/VR experience will go a long way in accelerating consumer adoption. While current generation AR/VR solutions consume between 10 and 50 Mbps of bandwidth, next-generation systems will require in excess of 200 Mbps. Increased bandwidth will enable higher video frame rates, stereoscopic audio, and more degrees of immersion (i.e., user interaction). While attaining higher bandwidth may be easier for some regions of the world, a significant gap remains. According to Akamai's most recent State of the Internet report, only 7.1 percent of global connections are above 25 Mbps, while global average connection speed are as low as 5.6 Mbps.[8]

High latency networks are also a major impediment to delivering rich AR/VR experiences. Latency greater than 20 ms can cause end users to experience motion sickness, could make the VR world seem unrealistic, and may fail to adequately accommodate new immersive experiences.

New technologies, such as 5G, Multi-access Edge Computing (MEC), and network slicing will be a part of the long-term solution for addressing the current networking impediments in the coming years. Edge computing, in addition, is also gaining industry attention as a means to reduce network latency and enable AR/VR experiences.

Education on AR/VR is very important at this stage of technology maturity. This paper provides an overview of these technologies the industry, adoption challenges, and role service providers can play in enablement and expansion.

3.0 State of the Industry

Many will describe VR and AR technologies as one thing, when actually they differ on use case application and the projected rate of broad adoption. The following description provides a brief overview as a definitional reference.

> **Virtual reality (VR)** is a technology that immerses a human into an artificial three-dimensional environment. Virtual reality systems do this by stimulating the human body's most basic senses of vision, sound, and touch. The experience typically requires a head-mounted display (HMD), which can be a pair of goggles that is worn by the user and connects to a laptop computer or gaming console. Optionally, smartphones are being placed in some goggles for a mobile, non-tethered (screenless) experience, enabling a lower cost solution, but lacking the quality of a tethered HMD.
>
> To create the VR experience itself, each eye is shown a slightly different view, fooling the brain into thinking it is inside a virtual 3D world. Users can experience an amazing sense of presence, scale, and depth. The virtual world can be explored from any angle simply by moving one's head or eyes. Movements are tracked by the HMD, and the view of the virtual world adjusts instantly. Haptic sensors on the hands or body stimulate the human body's touch and feel through vibrations and forced feedback. Finally, a high-end personal computing platform with a graphics acceleration unit is connected to the HMD to render the 3D virtual environment.

Augmented reality (AR) is a technology that is a subset of the VR solution. Typically, AR superimposes audio, visual information, or media on top of a user's normal, real-time field of vision. A typical AR system implements a pair of glasses with an integrated screen, battery, wireless connection, and audio output. AR aims to enhance users' interaction with the real physical environment, rather than separating them from it. The terms mixed reality (MR) and merged reality also use this definition, and in general, MR will further combine elements of many types of immersive and interactive systems.

VR and AR use similar technology for augmenting real-time human experiences. As noted earlier, the difference between the two solutions is the application that each technology serves. VR is typically tailored for indoor applications, like gaming, home theater, video, etc. AR is tailored more for mobile or nomadic applications. The strategy for the future is for both of these technologies to converge so that a fully-immersive VR experience can be experienced on top of real-time, real-world experiences.

The AR/VR market is early in its development and is fragmented, as evidenced by multiple, major VR platform vendors, each developing their own solutions. Distributing content to each of these platforms requires developers to support them, along with the associated development time and funding. Even so, the hype around the technology is very high, and a number of applications have been developed that are more for entertainment purposes, such as video games, than for commercial use cases. Investment in these segments remains significant, though it is off of its peak from early 2016. AR/VR dealmakers invested over $800 million dollars in Q2 2017, rounding out the more than $2 billion invested across 27 AR/VR sectors in the last 12 months.[9] The investments are flowing into next-stage experiences and technology developments, such as Intel's acquisition of Intel® True VR technology (Sports VR) and Apple*'s acquisitions of PrimeSense*, Metaio*, Emotient*, and Flyby Media*.

There are many different VR systems in the market today. They vary in capability and cost, and can be classified into two categories:

- **Tethered VR HMD Systems:** Tethered HMD systems are typically connected to a PC or processing platform via wires or cables. Use cases are geared toward PC gaming and provide high-end video graphics and high-resolution display capabilities.
- **Mobile VR HMD Systems:** Mobile HMD systems are typically headsets that house a smart phone. These can be cardboard solutions or fully-hardened plastic enclosures. The experience using these devices is typically limited to playback of 360 degree videos provided by content owners, like YouTube*.

Most solution delivery technologies for AR/VR, including HMDs, would benefit greatly from an improvement in quality. Simple, low-budget solutions, such as Google Cardboard*, provide easy access to low-end VR experiences that may be inadequate for high-reliability applications found in healthcare and industrial environments. Higher-quality HMDs are significantly higher in cost, a significant barrier to their adoption. New, compelling content, along with cost and functionality improvements, should eventually establish a broad, sustained base of development and consumption. New business models will have a hand in this as well, attracting new investment and paths to technology monetization.

Three to five year revenue forecasts for AR/VR show a continued dominance by hardware sales.[10] As the technology advances, other business models are providing additional opportunities. Advertising, for example, could be lucrative as AR/VR advertising itself becomes more immersive. Other business models that should see success include the monetization of mobile network data, subscriptions, premium apps, and eCommerce sales.

The form factors used for delivering the experience are determined primarily by how the devices are used and who will benefit from them. Common form factors include facemask-style devices that cover the field of view, glasses, helmets, and clip-ons. Functionality will vary and can be best served by matching the form factors with the services, software, and customer segments. Smartphones and tablets are used extensively given their convenience and availability in the global regions driving this technology.

The vendor landscape for AR/VR is also evolving and can be broken down into four major categories:

- **Ecosystem providers**: Google*, Microsoft*, and others provide HMD devices, operating systems, developer platforms, and content and app distribution channels. These vendors stand to gain the most from the mass market adoption of immersive technologies as they will not only be the device provider, but also content, app, and transaction mediators.
- **Components:** Semiconductor manufacturers that supply ingredients for immersive technology will go through a period of innovation to support the growing needs of immersive content, including personalization and social interaction.
- **App and content:** This category grew initially through video game development, but a number of companies are experimenting with business models that would enable new experiences. An example of this is Intel True VR technology, which brings VR immersive experiences to end users at sporting events. Intel True VR technology is described in greater detail later in this paper.

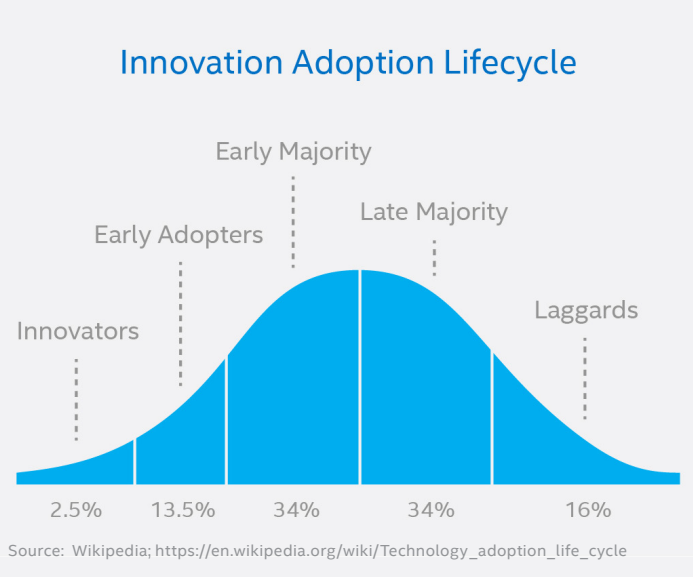


Figure 3. Technology Adoption Curve[11]

- **Service providers:** This group will provide the infrastructure for direct or over-the top (OTT) content delivery, seeking monetization avenues while assessing how to best to adapt to the growing demands placed on them by AR/VR. In addition, a number of service providers are now planning to take advantage of content for distribution from their parent companies (e.g., Comcast* and NBC Universal*) in order to deliver more immersive experiences in the future.[12]

The AR/VR markets are in the early, innovation stage as defined by the technology adoption curve shown in Figure 3. This is a reflection of the current offerings from within the vendor ecosystem, and their current and planned investments of solution vendors over the next few years. Many activities from within the vendor community are focused on increasing market awareness and education about the potential of AR/VR. This, along with the training (e.g., immersive media) for those who will be helping to overcome the identified impediments, should help increase the pace of technology adoption.

4.0 Market Opportunity

There are several HMD devices on the market that accounted for a total market revenue of $1.7B in 2016. The HMDs currently sold vary greatly in overall capability, video resolution, and price.[13] In 2016, most users seeking a VR experience went with Google Cardboard, a simple cardboard box that can be mounted to a smartphone.[14] The rest of the market has been developing higher-capability HMDs that are typically connected to a high-performance platform. In 2016, Samsung GR VR* led the way in unit shipments, followed by Oculus Rift* and HTC Vive*.[15]

HMDs are the predominant source of spending in the AR/VR market. Overall projected revenue growth for AR/VR is one reason for the enthusiasm in the industry. As shown in Figure 4, current estimates are for AR/VR headset sales to exceed $45B by 2021 with North America being the leading market.

Regionally, the VR market is expected to grow at a faster pace than AR in Asia/Pacific and North America, given the explorative state of AR and early investments by North American companies. Over time, AR growth may approach VR growth, but this remains to be seen. Figure 5 shows headset hardware shipment projections through 2021.

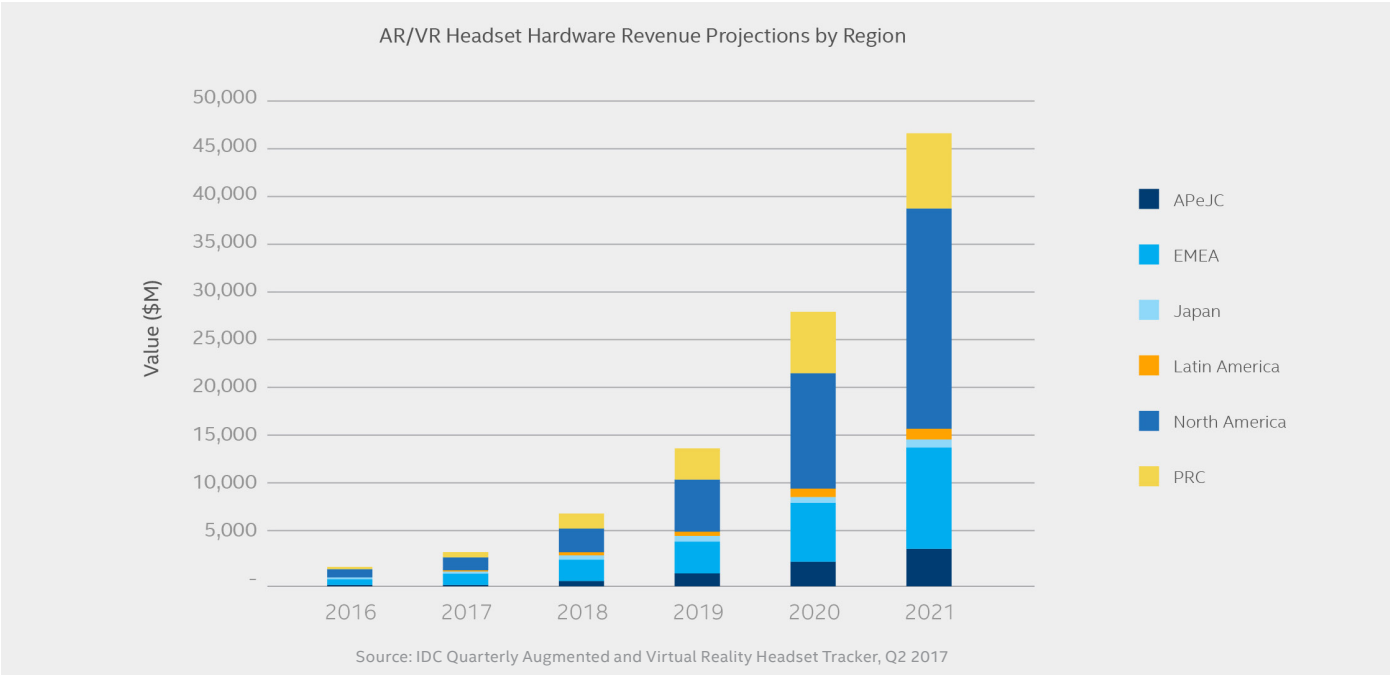


Figure 4. AR/VR Headset Hardware Revenue Projections

The hardware driving these revenue estimates are tethered and standalone HMD, including screenless viewers (i.e., VR headsets powered by a smartphone). By 2021, IDC estimates that while screenless viewers will still lead as the most shipped product to support AR/VR, tethered and standalone HMDs will have drawn much closer in terms of shipments and will continue to exceed screenless viewers in terms of average selling price (ASP) and revenue.[16]

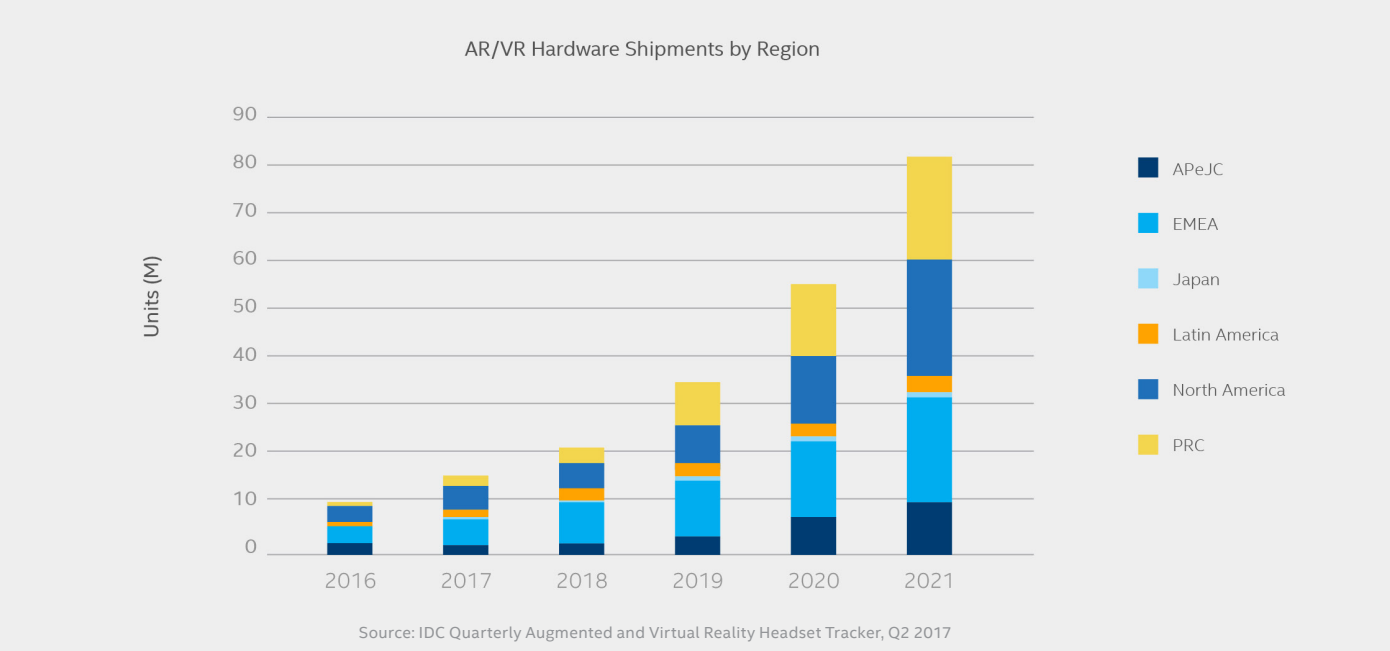


Figure 5. Worldwide AR/VR Hardware Shipments (units) by Region

While early adoption of AR/VR is primarily in the video gaming area, there are a number of emerging opportunities in both the consumer and enterprise/public sector that will help drive the projected growth.

Figure 6 lists application areas for AR/VR, along with revenue estimates for the software to support these use cases.[17tt]As shown in Figure 6, the market opportunity for AR/VR is significant and difficult to ignore. Revenue predictions for the enterprise and public sectors exceed $16B by 2025, while the consumer segment is projected to be about $19B.

For service providers, there are a number of ways to participate in this growing market. One of the most obvious ways is to deliver their video content through a VR headset, providing current consumers with new content.

The delivery of VR media content could potentially be through existing edge solutions in the home (e.g., set top boxes), mobile devices, or some combination of the two that may or may not include device tethering.

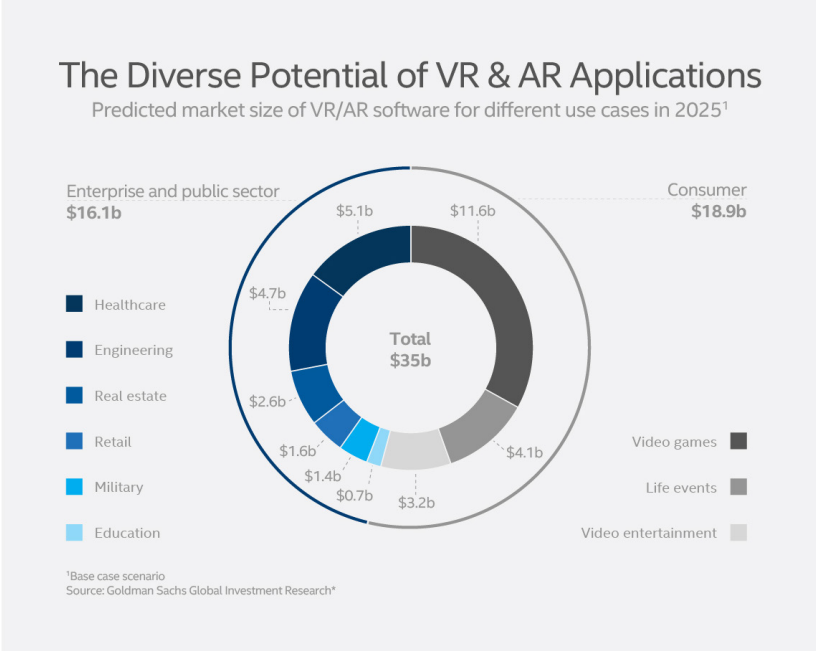


Figure 6. VR/AR Use Cases

Users would use credentials from service providers to access the video services, opening up new potential sources of content delivery revenue. There are a number of potential AR/VR applications that provide great scalability of existing media and video services and/or new ones that are more immersive in nature. These applications enable new revenue streams, increase existing revenue per user, and/or increase margins.

Examples of these use cases include:

- ***Spatial expansion:*** Service providers could develop a VR application that replicates a room, cinema, or other location, and provides the consumer the ability to experience live, on-demand, and other DVR content through a HMD. By using a service provider's existing web- based video product and an existing VR application, like Big Screen VR*, users could view the content of their PC screens in a home theater environment.
- ***Gaming quality of service:*** VR multiplayer online gaming is another service that a majority of VR consumers use. Service providers could provide a VR gaming service that guarantees the latency required for optimal, multiplayer online performance.
- ***VR On-Demand and Pay-Per-View Events:*** There is a large catalog of concert events available in the VR world. These events could provide service providers with a premium video revenue stream. Service providers could also charge for different locations within the virtual venue (e.g., front row seats), providing an enhanced experience for an incremental fee.
- ***Home office expansion:*** Current home offices consume valuable space for desks, computers, monitors, phones, video conferencing, and more. VR systems offer an opportunity for device consolidation, which reduces overall power consumption and form factor. To satisfy the bandwidth and low latency demands an office environment, service providers will need to offer 100+ Mbps or even Gbps throughput, a higher level of service that could potentially justify a higher average revenue per user (ARPU) and improved margins.
- ***Virtualizing customer service:*** VR-based tools for customer service representatives could allow for virtual debugging, allowing for quicker issue resolution and possibly eliminating the need to dispatch a technician. This same system could be used as a training tool, potentially saving companies time and money in training expenses.
- ***Augmented realit****y* in the field and production floor. A recent AGCO report stated that when factory workers were given AR glasses with step-by-step instructions on how to assemble a product, they were on average able to reduce production time by over 25 percent,[18] thereby increasing productivity. AR glasses can also be used to trouble shoot issues in the field, minimizing on-site support. Benefits include having direct communication with tier 2 or 3 technicians, and video and pictures of the experience at the site.

The combination of projected market spending, breadth of new use cases, and potential new revenue streams are major reasons the market is excited about AR/VR technology. A number of impediments remain in the way of market expansion, including significant ones in the networking infrastructure.

5.0 Infrastructure Challenges

As noted earlier, service providers play an important role in addressing the latency and bandwidth challenges associated with the AR/VR end-to-end (E2E) experience. This section describes these in more detail.

Reduced Latency

Typical latency requirements for the human brain to interpret the virtual environment and accept it as "real" is less than 20 milliseconds (ms), from the time the user interacts with the environment to the time the environment reacts. Latency exceeding 20 ms is noticeable to users. Today's VR experiences are attempting to manage latency through video stream synchronization and the coordination of limited user interaction. Overcoming latency challenges is much easier for non-interactive content that can use caching buffers, such as a streamed 360° video over a content delivery network (CDN). With content readily accessible in cache, high and inconsistent network latency has less impact on the quality of the experience.[19]

Increased user interactivity with the content poses new challenges. Low latency is required to ensure responsiveness for certain user interactions, such as virtually shooting an opponent in online multiplayer gaming, playing virtual ping pong/table tennis, controlling remote machinery, or interactively collaborating on a vehicle design. In these scenarios, visuals require a full rendering of the scene based on additional interactions. If the network is transporting the interaction information, then a reduction in latency is paramount to the experience.

Head movements, while wearing an HMD equipped with head tracking, is another type of interaction that adds more distinct latency requirements. Motion-to-photon (MTP) latency is the time between an action (a head movement) and a reaction (the display is updated based on the movement). When users move their heads, the brain expects an instantaneous visual and aural update, so delaying that even minutely can be problematic. A MTP latency less than 20 ms is currently targeted for many VR user experiences; studies have shown that achieving a MTP latency of less than 15 ms makes the delay imperceptible to nearly all users. Considering the strict HMD MTP requirements, ABI Research expects AR and VR applications will do much of the application processing on the device (HMD).[20] As network edge and cloud rendering capabilities increase, ABI research expects the processing will be intelligently split between cloud-based 3D rendering, which requires low network latency, and additional processing on the untethered mobile device to ensure high-quality visuals at a fixed, low MTP latency.

Given the projected market consumption of AR/VR experiences over the next few years, latency is then a key component that service providers must consider when designing their networks. Edge computing will play a role in helping to minimize latency effects by essentially placing cloud or edge components in between media source and consumption points. With movement towards cloud processing, edge computing will be extended beyond implementation in hub sites into potentially network nodes. Edge computing will need to be applied differently depending on the service and consumption end-point locations.

Increased Bandwidth

Bandwidth for AR/VR experiences is an additional challenge for service providers. Consider the typical video game or service only uses up to 5 Mbps of network bandwidth while most home services require far less than 1 Mbps. For today's interactive AR/VR experience, it is necessary to have a 10-50 Mbps wired connection between the processing platform and the HMD, especially at 2K/4K video resolutions.

Future VR architectures may render graphics in the cloud, which would require service provider networks to carry the 10-50 Mbps currently consumed by wired links. This is most likely unachievable without the heavy compression and information vectoring needed to reduce bandwidth usage.

The role of service providers has been critical in increasing the quality of current AR/VR experiences and enabling future ones. Their networks, which allow for a limited AR/VR experience today, will continue to be a critical component in keeping this growing technology moving ahead. Service providers should plan infrastructure improvements that address today's latency and bandwidth gaps in order to deliver acceptable AR/VR experiences to users.

6.0 Intel's Role

Intel's role in the development of the AR/VR market spans a range of investments and activities focused on addressing known impediments to broad adoption and global scale. Intel's work advances the end-to-end delivery of this technology across a wide range of use cases.

With leadership in client computing, data center technology, and network processing, Intel is uniquely positioned to address the multi-faceted challenges of AR/VR. Coupled with its investment in 5G, Multi-access Edge Computing, and visual cloud computing, Intel has an important role to play in the success and proliferation of AR/VR services. Understanding and proliferating specific AR/VR use case applications is important, and recent acquisitions of technologies such as Intel® freeD™ technology and Intel True VR technology are helping Intel do just that by delivering immersive experiences for sports.

It would be naive to think there is a silver bullet to solving the infrastructure challenges outlined in the previous sections; instead, a multipronged approach is needed to help the ecosystem realize the promise of AR/VR. This includes:

- Strategic investments that advance AR/VR technology in targeted use cases (e.g., Intel True VR technology).
- Content producer partnerships to understand technology workflow and distribution challenges.
- Active participation in standards organizations to help shape the AR/VR landscape.
- Ecosystem enabling to spur innovation and novel approaches to address bandwidth and latency performance issues.
- Ecosystem enablement using Intel's data center, networking, and visual cloud expertise and technology.

6.1 Strategic Investments

Intel freeD Technology

Intel freeD technology constructs volumetric images, creating a "virtual camera" that can show any view from any point on a field of play, using data from up to 38 standard 5K small form factor cameras (no specialized hardware) installed around the venue. These fixed cameras are deployed in a ring around the inside perimeter of a stadium and are connected via fiber to a rack of servers, which integrate the images captured from the highly-synchronized cameras. Currently, Intel freeD technology enhances sports broadcasts and digital highlights by enabling commentators to provide deeper analysis of replays with an unconstrained viewing perspective. Content captured with Intel freeD technology is selected and manipulated within a control room, typically located within the stadium. More information on Intel freeD technology can be found at: https://www.intel.com/content/www/us/en/sports/technology/intel-freed-360-replay-technology.html.

Intel True VR Technology

Intel True VR technology is an end-to-end, real-time VR delivery system that transports fans to the best seat in the house to experience the biggest moments of the season. It includes:

- Lightweight, portable camera pods with up to six pairs of stereoscopic lenses that capture 180-360 degree views deployed on and off the court at ideal vantage points.
- Servers that transcode and stich the data into a seamless real-time stream.
- Real-time transmission for multiple devices in multiple formats (mobile, web, and VR HMDs).
- Live and video-on-demand (VOD) content with the ability to allow users to switch camera angles for their own point of view (POV) or to view a fully produced stream with a director selecting cameras, replays, graphics, and VR commentary.
- End-user white label apps or software development kits (SDKs) to view content with added features such as real-time stats, playback controls, switchable viewing angles, virtual scoreboard, push notifications, and analytics.
- Intel True VR technology supports a VR experience on Samsung Gear VR* and Google Cardboard, a 2D panoramic view on Apple iOS* and Android*, web, and social platforms such as Twitter360*, FB360*, and Youtube 360*.

The Intel True VR technology-based system does not require a permanent install at the venue. On the day of the event or the day before, it is typically set up with a mobile control room van parked either inside or outside the venue. The system has been deployed at dozens of live events in the U.S., including the NFL* (football), NCAA March Madness* (basketball), MLB* (baseball), and concerts. More information about Intel True VR technology can be found at: https://www.intel.com/content/www/us/en/virtual-reality/true-vr-technology-overview.html.

6.2 Content Partnerships

Intel is working with major sports organizations to enhance the sports experience and address the content challenge. Overcoming the technical barriers is not sufficient; the user experience and content must be sufficiently compelling to create new revenue opportunities. For any embryonic service, pathfinding is an essential step to verify the practical potential of the service. Considering the implications AR/VR will have for traditional production and distribution workflows, collaboration from all parts of the workflow is essential.

To that extent, Intel has partnered with the NBA*, NFL*, IOC*, and the PGA Tour* to help deliver AR/VR experiences to a broad audience. These events will provide valuable insights into the business and infrastructure changes required to make AR/VR a viable business opportunity. Further background on these engagements, and information about how Intel is changing the way sports media is being consumed, can be found at: https://www.intel.com/content/www/us/en/virtual-reality/true-vr-technology-overview.html.

6.3 Standards Participation

Intel participates in a number of media standards bodies and industry forums. This participation is in the capacity of working group leadership and/or contributor. Intel's primary goals in working within the media standards community is to promote industry interoperability, ensure use case support, improve coding efficiency, and to discourage 3rd party patents in order to encourage market adoption.

The areas of Intel's participation support current and emerging immersive experiences and include the following:

- **360 Degree Video or Three Degrees of Freedom (3DoF).** Intel is working to further enable immersive media experiences by helping to advance compression standards, including High Efficiency Video Coding (HEVC) and the Omnidirectional Media Application Format (OMAF)[21] developed by the Motion Picture Experts Group (MPEG).[22] The work within MPEG is part of their MPEG-I (MPEG Immersive) efforts. Intel is also leading the distribution working group within the VR Industry Forum, which is focused on providing guidelines for the use of viewports in graphics rendering.
- **Three Degrees of Freedom Plus (3DoF+).** Intel is participating in future releases of OMAF that will improve stereo and depth in cross-platform media distribution.
- **Six Degrees of Freedom (6DoF).** Intel continues to monitor the development of MPEG's efforts with Point Cloud Compression, thereby enabling 3D to multiple 2D projections and Light Fields, which will add multi-view and depth as an extension to H.266, targeted for release in 2021.
- **Multi-access Edge Computing (MEC).**[23] Intel contributes to work in the European Telecommunications Standards Institute (ETSI) efforts around MEC, which will enable new vertical business segments, such as AR. Standards efforts will help reduce technology impediments and enable new revenue streams for operators, vendors, and third parties.

6.4 Ecosystem Enabling

Intel® Network Builders (INB)

Intel recognizes that enabling network transformation to support AR/VR will require a strong ecosystem of partners. The Intel® Network Builders program (http://networkbuilders.intel.com) connects service providers and enterprises with infrastructure, software, and technology vendors that are driving new solutions in the AR/VR market. Intel seeks to increase ecosystem alignment and build a strong and sustainable market advantage for its members through solution-centered ecosystem collaboration based on Intel® architecture. Today, there are more than 260 Intel Network Builders partners, a growing number of end-user members, and an increasing number of opportunities for collaboration.

6.5 Data Center, Networking and Visual Cloud Innovation

5G – 5th Generation Mobile Networks

In addition to providing faster speeds, 5G networks will also enable new use cases, such as the Internet of Things (Internet-connected devices), as well as broadcast-like services. Intel strongly believes the advent of 5G will be an epoch in the industry that provides the ability to address a number of the primary network challenges previously identified to the rollout of AR/VR (i.e., reducing latency and providing greater bandwidth). From Intel's perspective, 5G is far more than a next-generation wireless standard; it is a key step on the path to 50 billion connected devices worldwide. To help bring this technology to its full potential, Intel is investing in developing new technologies, advancing open source solutions and standards, enabling an open ecosystem, and collaborating with end users.

More information about how Intel solutions are powering 5G can be found at: https://www.intel.com/content/www/us/en/wireless-network/5g-vision-document.html.

Multi-access Edge Computing (MEC)

With the expected exponential growth in the Internet of Things (IoT) and 5G, increased intelligence and processing power will inevitably migrate to the edge of the network. MEC is a network architecture that enables cloud computing capabilities and an IT service environment at the edge of the network (Figure 9). By migrating services closer to the subscriber, network congestion and application response times are reduced, delivering a better quality of experience (QoE) to the subscriber. This approach also lowers both the volume and the peak traffic levels on the backhaul links, allowing service providers to add resources to meet the growing demand for data without upgrading their backhaul links.

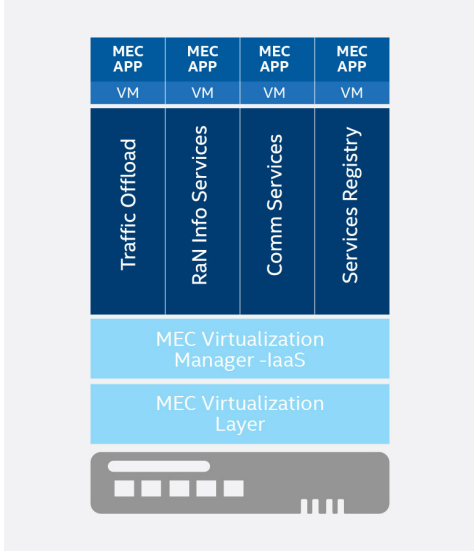


Figure 7. MEC Architecture

MEC technology helps reduce latency and enables flexible and rapid deployment of new services such as AR/VR. At Shanghai Mercedes Benz Arena*, Intel, Nokia*, China Unicom* and Tencent* recently demonstrated a joint project that utilizes 5G and MEC to bring a new level of fan experience.[24]

Using Nokia Multi-access Edge Computing (MEC) technology, powered by the Intel® Xeon® processor and deployed as part of China Unicom's Edge-Video Orchestration (EVO) network, the solution enabled the videos captured within the venue to be stored in a dedicated edge cloud; spectators in the stadium could then follow four different HD channels in real-time on their mobile devices. Such demonstrations help explain why MEC is being embraced by service providers and standards organizations as a new and innovative way to deliver content and services to subscribers. The expected roll-out of MEC will be key to the future success of AR/VR.

Intel® NEV SDK

The Intel® Network Edge Virtualization (NEV) SDK provides a network functions virtualization (NFV) platform targeted for Multi-access Edge Computing application and services. The NEV SDK includes an Intel® Atom™ processor-based or Intel Xeon processor-based server that is fully configurable with real-time virtualization software and Intel's Edge Computing reference libraries for directing radio traffic information to virtual machines based on policy settings. The NEV SDK comes with a full tool suite for testing and profiling the applications. For more information about the Intel NEV SDK go to: https://networkbuilders.intel.com/network-technologies/nev.

FlexRAN

Intel's FlexRAN is a virtual Radio Access Network (vRAN) software reference platform. Functions include virtualized Layer 1 through Layer 3 processing that scales to many cells. FlexRAN is based on general-purpose Intel processors that scale from small to macro and can be used across many use cases. FlexRAN is an off-the-shelf, virtualized platform containing general-purpose Intel® processors (Intel Atom processor or Intel Xeon processor), I/O, and FPGAs that enable dynamic network slicing and a high level of flexibility with programmable on-board features and memory.

FlexRAN allows Intel and its partners to enable latency-sensitive services while improving quality of experiences at lower costs. This has resulted in a number of successful proof-of-concept designs that demonstrate virtualized radio access network (vRAN) with MEC running on the same server, supporting latency-sensitive applications, like AR/VR.[25]

Visual Cloud Computing

The visual cloud is the implementation of visual-computing applications on cloud computing architectures, cloud-scale processing and storage, and ubiquitous broadband connectivity between connected devices, network edge devices, and cloud data centers. It comprises four application areas: media creation and delivery, cloud graphics, media analytics, and immersive media (e.g., AR/VR).

Current AR/VR solutions are a marriage of on-premise processing and cloud processing. AR/VR services are expected to evolve along these lines, with some processing migrating from the cloud to the edge. The compute required at each stage will have diverging requirements, so a portfolio of technologies will be needed: large clusters of general-purpose compute and storage in the cloud to power-efficient compute and acceleration at the edge.

Intel is advancing the visual cloud through enabling technologies in hardware, software, and platform features. For more information on visual cloud computing and Intel supporting technologies, visit: https://www.intel.com/content/www/us/en/cloud-computing/visual-cloud.html.

7.0 Recommendations and Considerations

As noted throughout this paper, in addition to the great opportunities associated with the rollout of AR/VR, there are a number of impediments to broad AR and VR adoption that range from the initial capture of the content across the spectrum to the delivery to the end user. The following are recommendations for the industry, with special attention paid to the communications service providers (CSPs):

1. **Increase organizational expertise.** Recruit immersive media developers and experts to develop use cases, accelerate projects, maintain consistency, and improve both business and technical organizational knowledge.
2. **Focus on delivering an improved end-user experience.** Make iterative improvements to products in order to improve the user experience, which may entail making adjustments to end-to-end workflows.
3. **Evolve how AR/VR experiences are consumed.** Evolve the consumption method to balance increased quality and affordability. Smart phones are convenient, but they were not originally designed to optimize the AR/VR experience. HMDs provide greater immersive capabilities, but their high cost has limited adoption to technology enthusiasts and early adopters.
4. **Address end-to-end network limitations.** Reduce network latency and increase bandwidth to deliver better immersive media experiences, as presented earlier:
    - Increased Bandwidth – The average global Internet connectivity was 7.2 Mbps in the first quarter of 2017, with the U.S. averaging over 18 Mbps.[26] Gigabit per second service to the home is progressing while the availability of 10 Gbps services are just starting in a limited number of locations.[27] In the next couple of years, advanced VR solutions incorporating 6DoF could be a service that would require deployment of 10 Gbps services to the home to enable this type of experience.
    - Reduced Latency – Meeting an end-to-end latency goal of 5 ms or less severely limits the distance allowed between a HMD device and its cloud-rendered data, which is unrealistic for global content delivery. Typical network buffering implemented in every switch and router along the data path adds to this problem.

For service providers, there are technologies being developed and explored that should be considered in overcoming these network challenges. 5G, edge computing (including Multi-access Edge Computing), and network slicing are examples of technologies to consider.

With early trials underway, 5G promises to provide a solution that would help address network latency. ABI Research anticipates 5G will bring about a 10 times improvement in throughout, a 10 times decrease in latency, a 100 times improvement in traffic capacity, and a 100 times improvement in network efficiency compared to 4G.[28] New VR applications and media formats, such as 360-degree video, 6DoF video, and stereoscopic video, will all be aided by the broad roll-out of 5G from 2019 onwards.

When considering the downlink (i.e., media consumption) challenges with the network, edge computing is a promising approach. By bringing the graphics rendering closer to the point of user consumption, the challenges associated with end-to-end roundtrip latency could be significantly reduced. Communications service providers would deploy these edge node servers in a hub or a central office, located for geographic optimization, to ensure latency targets are met. Operational considerations for such solutions, such as power, available real estate, and cooling, would of course need to be thought through. One path to minimize potential operational burdens of this approach is to adopt Remote PHY technology utilizing NFV and software-defined networking (SDN). A significant number of service providers are already adopting NFV and SDN approaches to reduce cost and increase network functionality.

Guaranteeing end-to-end quality of service for latency-sensitive applications will be one of the benefits delivered by network slicing. Simply stated, network slicing allows service providers to create multiple, logical networks that are assigned to different services, each running over a common physical infrastructure. The technology is considered a key value enabler for 5G use cases and is being analyzed by service providers for possible implementations, new services, and financial benefits.[29]

8.0 Summary

AR and VR are high growth markets with headset hardware sales expected to exceed $45 billion by the year 2021. Though very much in the in early product development stage, the segment's growth will be rapid and fueled by a wide range of use case applications that extended beyond gaming and into such markets as healthcare and industrial engineering. The expected impact of this technology is going to be dramatic and is poised to have a lasting impact on how people interact with the world and with each other.

Achieving this AR/VR vision will require overcoming a number of technology adoption impediments such as improved consumption devices, a lack of compelling content, high end-user device cost, and network impediments, including high latency and low bandwidth. For service providers, addressing the bandwidth and latency deficiencies associated with delivery of immersive media will be increasingly important for future content passing over their networks to ensure a quality end-user experience. 5G, edge computing (including MEC), and network slicing are technologies that will help in that endeavor.

9.0 Call to Action

- To learn more about Intel's® technology for VR, visit https://www.intel.com/content/www/us/en/virtual-reality/virtual-reality-overview.html.
- To learn more about Intel® Network Builder partners for AR/VR and other products, visit https://networkbuilders.intel.com/solutionscatalog.
- To learn more about Intel® TrueVR technology and current partnerships, visit https://www.intel.com/content/www/us/en/virtual-reality/true-vr-technology-overview.html.
- To learn more about Intel's vision for 5G, usage models, and product plans, visit https://www.intel.com/content/www/us/en/wireless-network/5g-vision-document.html.
- To learn more about Intel's investment in the visual cloud, visit https://www.intel.com/content/www/us/en/cloud-computing/visual-cloud.html.
- To learn more about how Intel® network solutions are helping enterprises, and communications and cloud service providers solve complex business challenges, such as media delivery, visit www.intel.com/network.

10.0 Key Terms

Virtual Reality Terms

This section defines the terms related to virtual and augmented reality.

10.1.1 Head-mounted Display (HMD)

A head-mounted display (HMD) is a display device worn on the head or as part of a helmet to deliver the VR experience. It can have a small display optic in front of one (monocular HMD) or both eyes (binocular HMD). A HMD has many uses, including gaming, aviation, engineering, and medicine.

10.1.2 Virtual Reality (VR)

Virtual Reality (VR) is a technology that immerses a human being into an artificial, three-dimensional environment. VR systems do this by stimulating the human body's most basic senses of vision, sound, and touch. Consumption of the experience typically occurs through the use of a HMD.

10.1.3 Augmented Reality (AR)

Augmented Reality (AR) is a technology that is a subset of the VR solution. Typically, AR superimposes audio, visual information, or media on top of a human being's normal, real-time field of vision. A typical AR system implements a pair of glasses with an integrated screen, battery, wireless interface, and audio output.

10.1.4 Degrees of Freedom (DoF)

Degrees of Freedom is the number of ways an object can move within a space. There are a total of six degrees of freedom in a three dimensional space. The six DOF can be divided into two categories: rotational movements and translational movements. Each category has three DOF. Oculus Rift* (Platform) and SteamVR* HMDs have six DOF. Both orientation tracking (rotation) and positional tracking (translation) are required to have a truly immersive VR experience.

10.1.5 Field of View (FoV)

Field of view, or the extent of the observable environment at any given time, is one of the more important aspects of virtual reality. The wider the field of view, the more present the user is likely to feel in the experience. There are two types of FOV that form human vision.

10.1.6 Motion to Photon Latency

Also known as the end-to-end latency is the delay between the movement of the user's head and the change of the VR device's display reflecting the user's movement. As soon as the user's head moves, the VR scenery should match the movement. The greater the delay (latency) between these two actions, the more unrealistic the VR world seems. To make the VR world realistic, the latency of VR systems should be between 20 ms and 7 ms.

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