HUAWEI

PREPARING FOR A CLOUD AR/VR FUTURE

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CONTENTS

Augmented and virtual reality: peering into the future

Augmented and virtual reality (AR and VR respectively) are transformative technologies poised to revolutionize the consumption of content and communication, not only within the consumer space but also in many commercial and enterprise markets. This white paper will discuss how today's nascent AR and VR market will develop and call out the essential technologies, such as. 5G, and milestones needed for the industry to reach its fullest potential. Wireless X Labs and ABI Research estimate AR & VR will reach US$ 292 billion by 2025 (US$ 151 billion for AR and US$ 141 billion for VR).

As the market evolves experimentation and adaptation will allow service and content providers to both leverage existing business models and introduce new services that fully maximize the potential afforded by AR, VR and supporting technologies. Augmented and Virtual reality experiences are currently relatively separate and have clear boundaries, in the future, however, a continuum of technologies and experiences will exist between augmented and virtual reality.

1.1. Establishing the AR/VR Reality Spectrum

The Reality Spectrum segments the market across the AR and VR landscape, starting with no virtual assets or content (reality) to fully immersed VR (see below).

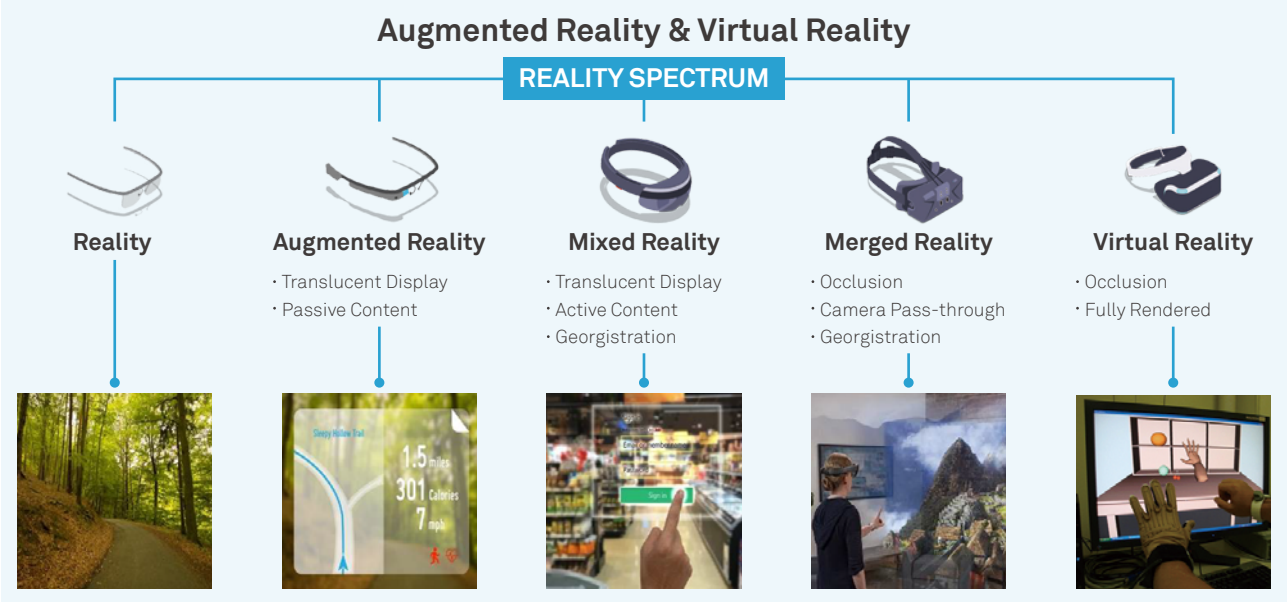


Figure 1: The AR & VR Reality Spectrum
(Source: Wireless X Labs, ABI Research)

1.1.1. Augmented Reality

Augmented reality supplements or enhances the user's view of his or her real world environment. To date most of the activity in the AR HMD market has come from the commercial and enterprise spaces but mobile AR (e.g. used with smartphones and tablets) and future consumer-friendly HMDs will yield stronger growth opportunity outside of the professional markets. AR smart glasses are segmented further into monocular and binocular applications.

1.1.2. Virtual Reality

Virtual reality differs from AR in its goal to offer a deeper, more immersive experience that in practice typically occludes the user's view of the real world, instead moving the user's perception into a separate and often disparate virtual space. The VR market is further segmented into mobile (uses a smartphone for screen and processing/sensors), Tethered (external processing, console or PC), and standalone (all-in-one device).

Mobile VR is best exemplified by Google Cardboard and Daydream and Samsung's Gear VR. Pricing for these devices are low with most solutions priced at $100 or less – these devices are also used in promotional events. Current interactions are limited to seated experiences (3 degrees of freedom, also known as "3DOF") but room scale (or 6DOF) experiences will help bridge the gap between mobile and the other categories.

Standalone VR includes both x86 and mobile hardware configurations (e.g. Qualcomm Snapdragon Platform) and represents an all-in-one package. Pricing for the VR device is comparatively high (to mobile HMDs) but low when compared to high-end PC and tethered VR packages. China is an early leader for standalone devices but this facet of the market is anticipated to have the highest CAGR among the market HMD segmentations. Product life cycles are likely to mirror tablets allowing OEMs to balance cost and performance based on target applications and product segmentations.

Tethered VR uses external processing (e.g. PC) and represents the pinnacle of the current VR experience within the home and often within the commercial space as well. Pricing is at the high end when the entire package is considered, but Microsoft is enabling OEMs to launch a mid-range tethered HMD lineup – incumbents like Oculus have also cut prices of launch products as well. Lower price points derived from less expensive HMDs and PCs (reduced minimum requirements) will drive enterprise visualization and design, more so than PC gaming.

1.1.3. Mixed and Merged Reality

Despite these differences, AR and VR fundamentally bring together both the real and virtual into one common shared experience and advancements in technology will further generate hardware and use cases that look far more similar than disparate; hence the addition of mixed and merged reality segmentations within the reality spectrum.

Mixed and merged reality devices provide similar end user experiences but due to current limitations in technology approach the market with influences from either the AR or VR ends. PC manufacturers like Acer and HP for example will release merged reality HMDs that align closer to VR devices, while mixed reality solutions from companies like Meta and Microsoft's Hololens carry more characteristics associated with AR.

1.1.4. Market Potential

In 2016 the combine AR and VR market passed US$ one billion and it is poised for growth with a 70.9% expected CAGR from 2017 to 2025 – VR will have a slower CAGR at 60.9%, compared to AR at 90.4%.

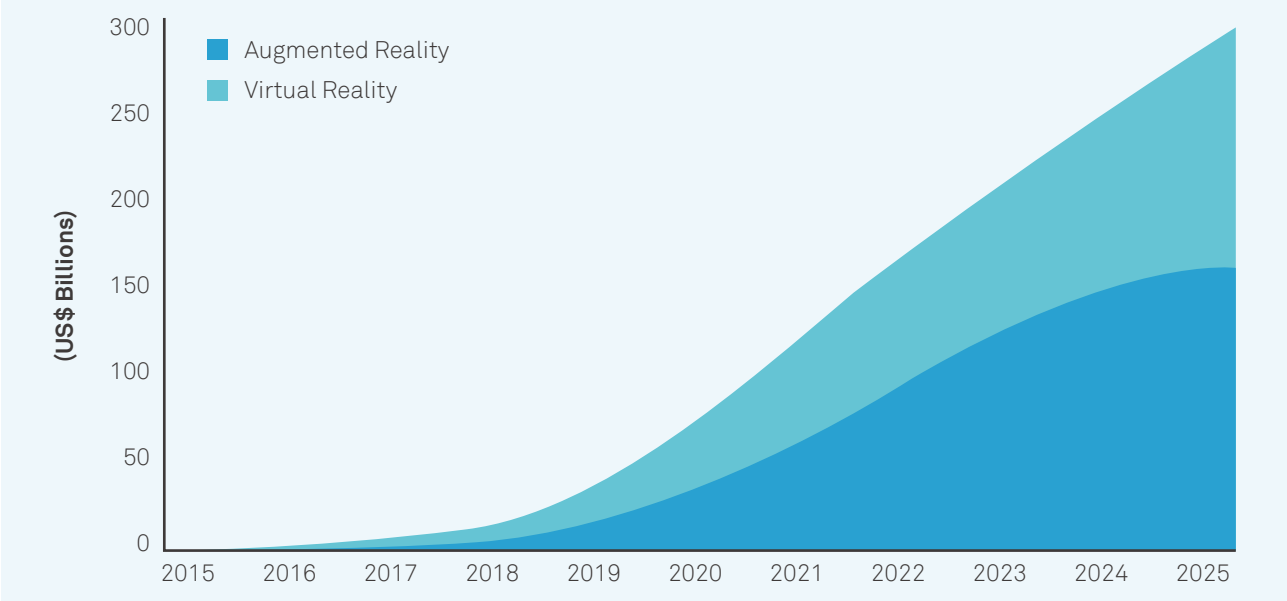


Chart 1: Total Augmented and Virtual Reality Market Revenue World Markets, Forecast: 2015 to 2025 (Source: Wireless X Labs, ABI Research)

A careful balance between consumer and education and enterprise applications is necessary, as companies will leverage common technology platforms with different content and go-to-market strategies. Towards the latter years of the forecast and evolutionary path discussed in the next section, VR and AR will begin to merge, creating opportunities for MR applications. The largest VR unit volume shipments will shift from low-cost mobile reliant HMDs (e.g. Cardboard units), through to mobile promotions (e.g. Samsung Gear VR, Google DayDream) toward standalone HMDs. In the AR market, volumes of smart glasses will expand with more off-the-shelf applications and lower cost HMDs – in addition MR devices like Microsoft's Hololens will also extend the reach of the AR market. In total the AR/VR market will expand to nearly 300 million units in 2025, with nearly 250 million VR HMDs compared to 50 million smart glasses.

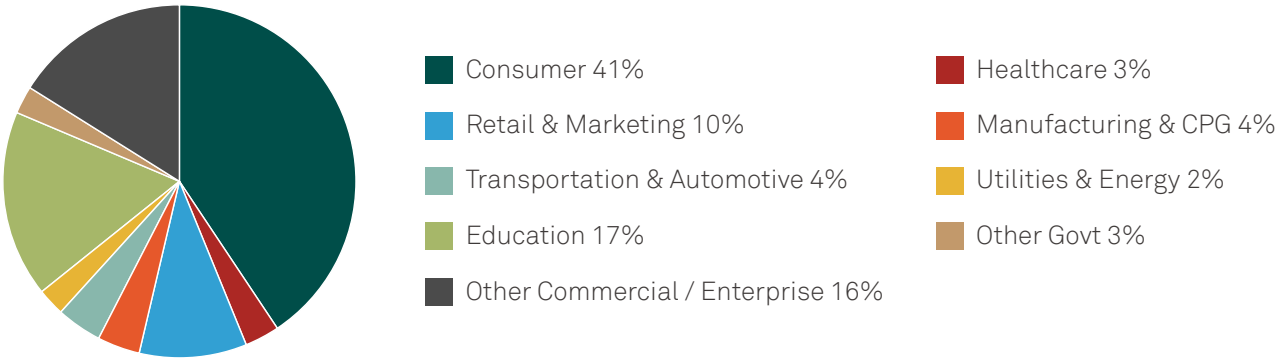


Chart 2: Segmentation by Verticals, AR & VR HMD Shipments World Markets, 2025
(Source: Wireless X Labs, ABI Research)

The consumer segment is expected to remain the largest category with consumer AR hitting an inflection point in 2019/2020 with accelerated growth as pricing and form factors become more consumer-friendly. Similarly VR will find stronger traction among particular verticals like Education as lower priced mobile units expand by 2025 facilitating interactive and immersive learning. The eventual growth of MR applications and productivity will further penetration rates into other businesses and government entities.

In the software and services component of the VR market the consumer segment is likewise expected to hold the largest segment of the market with over 50% share. By 2025 gaming is anticipated to remain the largest VR market category at 35% of total VR software and services revenue (over US$ 30 billion), but its share will have declined from 54% in 2016. Video, which will have a slower start than the gaming market, will grow to 19% of the software/services market, passing US$ 16.6 billion in 2025.

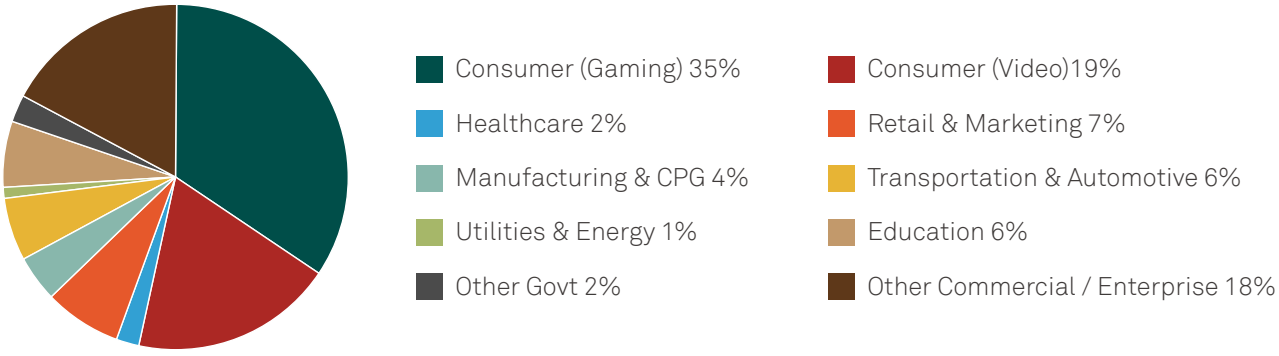


Chart 3: Segmentation by Vertical, VR Software & Services Revenue World Markets, 2025
(Source: Wireless X Labs, ABI Research)

Throughout the forecast window leading up to 2025 a progression of evolutionary stages will take place that will help shape the development of both the AR and VR markets (these are discussed in greater detail in the next section). A key component of this development is connectivity, both local and to the cloud. In today's market a significant amount of content (particularly non-video) is downloaded and delivered as apps. In the coming years the download model will cede ground to cloud delivered content and services, eventually giving rise to cloud AR/VR. Mobile VR is a natural fit for cloud distribution since these devices (due to smartphones) typically have both Wi-Fi and cellular connectivity and for the purposes of this white paper these features are assumed to be ubiquitous for this device class.

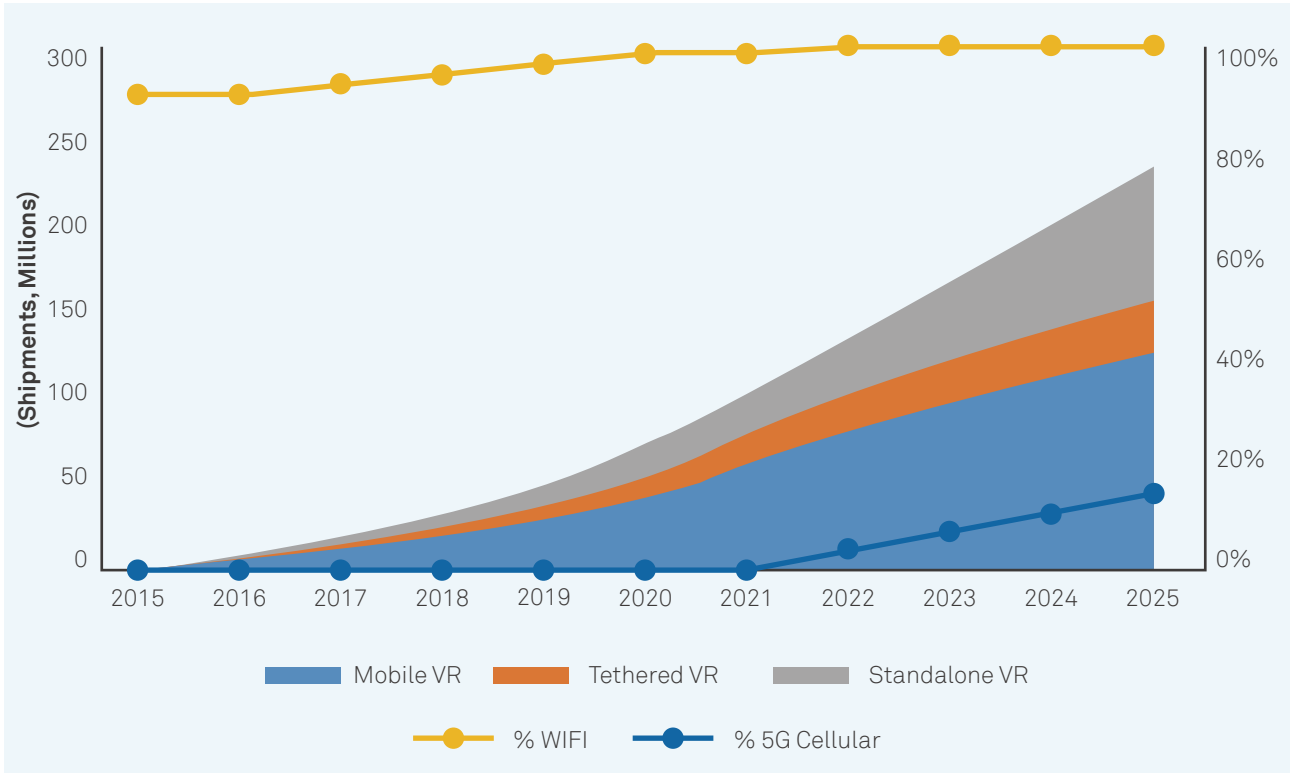


Chart 4: VR HMD Shipments by Connectivity World Market, Forecast: 2015 to 2025
(Source: Wireless X Labs, ABI Research)

Standalone VR HMDs will start to gain momentum starting most significantly in 2018 and while early models (like those available today) will favor Wi-Fi connectivity only (over cellular) the expanded use cases tied to mixed and merged reality will create additional value – form factors must also evolve to better fit out-of-home and in-public use cases. 5G in both cases will begin to ram up in 2020 to coincide with more wide-scale rollouts, but if the 5G timeline is accelerated the availability of 5G enabled HMDs will similarly arrive sooner.

2. VR technology and evolutionary path – emergence and rise of cloud AR/VR

It is an inevitable trend to provide cellular network-based superior AR/VR experience anytime and anywhere, as well as cloud content publishing and rendering with lower requirements for terminal devices. With the progress of AR/VR technologies, evolution of transmission networks, and enhanced cloud processing capability, Wireless X Labs proposed five stages to define the cloud AR/VR evolution. To reach its full market potential several key technological milestones must be satisfied – 5G is one such key enabler, enabling cloud AR/VR to help solve device and cost constraints pressuring AR and VR.

Cloud AR/VR Evolution and Connectivity Requirements

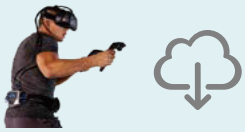
	Stage 0/1		Stage 2	Stage 3/4
VR Applications & Technical Features	**PC VR**	**Mobile VR**	**Cloud Assisted VR**	**Cloud VR**
				
	Gaming, Simulation (motion processing and rendering in a local computer)	360°video, Education (panoramic video download and motion processing in smartphone)	Immersive content, interactive simulation, Visualization/design (cloud-based motion processing, FOV(+) video streaming)	Light field video spatial experiences (cloud-based motion processing and real-time CG rendering, FOV(+) video streaming)
AR Applications & Technical Features	**2D AR**		**3D AR/MR**	**Cloud MR**
				
	Assembly instructions, gaming, location-based, remote work, visualization for retail/marketing (Local images and text overlay)		Holographic visualization with increasing universe size. Highly connected public safety AR applications (Image upload, cloud-based multimedia response)	Cloud-based mixed and merged reality applications Increased user density and connectivity (Image upload, cloud-based image re-rendering)
Connectivity Requirement	**Primarily Wi-Fi Connectivity**	**4G and Wi-Fi Streaming to 20 Mbps 50 ms latency**	**4.5G Streaming to 40 Mbps 20 ms latency**	**5G Streaming to 100 Mbps - 9.4 Gbps 2-10 ms latency**

Figure 2: AR/VR Connectivity Requirements and Evolutionary Stages
(Source: Wireless X Labs)

As the AR and VR stages rollout out the evolutionary changes to content, services, and use cases (e.g. seamless usage from home/office to public) will place increasing demands on bandwidth and continuity of service across increasing distances and locations. While current generation mobile and fixed networks can support today's AR and VR applications, hardware arriving in the coming years will put additional strain on networks already getting pushed by streaming video and eventually exceed the capabilities of today's mobile (and in some cases fixed) networks. In addition a shift from downloaded content to reliance on the cloud will further necessitate reliable and pervasive connectivity, particularly in populated areas where features like location based services and advertising will take root.

The stages discussed in this white paper are established based on current market expectations and rollouts, but the timeline could shift if companies and network operators deploy new technologies more/less aggressively than currently anticipated.

2.1. PC VR, Mobile VR and 2D AR

In the current VR and AR markets Head Mounted Displays (HMDs) enabled seated/standing VR on mobile devices and room-scale experiences using outside-in tracking for tethered devices – most content outside of streaming 360 video is downloaded and processed locally (either on a smartphone or PC). The AR market in contrast has a more diverse set of products that span a larger range of generational stages, but current market traction still favors hands-free tablet replacement (monocular smart glasses with micro-displays using waveguides) with predominantly 2D and some relatively constrained 3D elements for most applications.

Today's VR market is led by Google and Samsung on the mobile front and Sony, HTC, and Facebook/Oculus for tethered HMDs, There are a significant number of HMD suppliers, particularly in large markets like China where app stores and platforms from multiple vendors are tested with less barriers. Pricing and limited content along with mixed consumer experiences are growing pains not unique to VR, but nonetheless slow uptake and adoption.

The AR market has better diversity and some separation between hardware and software platform providers – Vuzix, ODG, Google, Microsoft, and Epson for instance are among the smart glasses market leaders. Companies like PTC, Wikitude, Upskill and Atheer are leading platform providers (Apple's ARkit also holds strong opportunity). Meanwhile, some companies work on integrated systems such as Microsoft (Hololens), Google (Glass/Android) and captive platforms (ODG/ReticleOS),

Both markets currently lack industry-wide standards, which in the place of these guidelines the market is pushed forward by many of the aforementioned market leaders. Over the course of the subsequent stages more universal guidelines, if not standards, will begin to shape and codify a relatively fragmented market.

2.2. Cloud Assisted VR and 3D AR/MR

Stage 2 marks the first evolutionary changes to hardware, software, and services, with an increasing role for cloud-based motion processing and delivery of images with an appropriate field of view (FOV) based on the motion. In the VR space in particular the hardware will start to transition from seated/standing experiences to full room-scale applications, accomplished through inside-out tracking (either through the use of external cameras or embedded vision solutions like Tango or Intel's RealSense). In addition to room-scale tracking using indoor positioning will also start to play a larger role in both AR and VR.

For services and content this means increased levels of interactivity and immersion which will lead to more premium-pricing of content. Advertising in VR, which is currently highly experimental with virtual objects/portals to traditional ads running within virtual environments, will also become more formalized once content creators and ad agencies determine which kind of ads (and what delivery mechanisms) are most effective in matching consumers' accepted interactions with advertisements. Google and Facebook for example have presented developers and content owners with new platforms to further explore monetization (e.g. displaying 2D videos/ads in a VR environment, social spaces, etc.). While VR use cases will remain very much within homes and offices, AR will have already expanded to the public arena and the market opportunity assignable to these public spaces will grow in lockstep with the spread of consumer grade smart glasses and AR applications for smartphones – marking the start of mixed reality.

The social impact of these technologies will also start to become visible as educational systems increasingly use VR to create immersive learning experiences that help elicit wonderment among younger students, making lessons more impactful and engaging. Academic programs and initiatives, such as those designed to push STEM, will have greater impact with VR and AR by inspiring the students' curiosity and desire to learn.

While not intended to eliminate first hand experiences virtual experiences will allow students to explore regions and cultures well beyond what is feasible in a typical school setting. Higher education will likewise benefit from AR and VR with advanced lab work and more immersive teaching scenarios better prepare students for real-world engagements and activities.

These interactions will also plant the seed for future professionals to view AR and VR as tools for the workplace. The belief that AR and VR are the future of computing is real and if these technologies are to live up to this vision the groundwork will start in Stage 2. This stage will be rife with experimentation but technologies such as light field (accounting for all of the light rays in a scene and capturing information about intensity and direction of light, enabling spatial mapping) will start to address lingering issues such as the "vergence" and "accommodation" problem. Vergence refers to the eyes converging and diverging as objects move closer and further away from the viewer, while accommodation refers to the changing of focus on objects as distance varies. The vergence-accommodation problem occurs because the focal plane in most VR and AR devices is fixed, meaning the usually coupled vergence and accommodation become uncoupled as virtual objects move closer and away from the user.

As part of these innovations efficiencies in content processing and distribution will help reduce some of the hurdles present with current distribution channels – hybrid cloud processing for example can greatly diminish some of the processing and bandwidth requirements for room scale video experiences and help address network latency. Mobile Edge Computing (MEC) for example enables cloud computing at the edge of the cellular network and it can be used for content distribution (e.g. at a stadium or concert – premium passes with showing multiple viewing angles could be sold) among other services at public locations and enterprises. These technologies can help bridge the gap until 5G arrives and be used in conjunction with next generation networks.

2.3. Beginning of Cloud AR/VR

Stage 3, which represents the start of Cloud AR & VR, begins three years out and extends to 2022, marking the start of the critical 5-10 year window for AR and VR. Unlike the second stage which only involves video matching, this stage introduces cloud-based real-time rendering of Computer Graphics (CG) virtual images. Instead of depending on the powerful GPU of a game console or local computer, cloud rendering AR/VR technology allows user to stream video games or virtual contents from cloud server just like any other streaming media. It will open up an opportunity for offering more varied and interactive VR contents and make the user device lighter, cheaper and freedom from the tether. During this period new technologies such as light field displays and room-scale video experiences are anticipated to have entered and started to gain traction, while more mainstream devices will have at minimum 8K resolution. Throughout the first three stages, screen resolution will increase incrementally with the ultimate goal of reaching a threshold where the virtual objects are essentially indistinguishable from the real world –eliminating current issues in VR displays like the screen-door effect or pixilation.

Technologies like eye tracking and foveated rendering (reduces image quality in peripheral vision to limit demands on data and processing) are essential ingredients for these high resolution HMDs but bandwidth and latency requirements will push markets to require 5G networks. Many telcos are already preparing for a 5G future that will allow for more robust and fully featured services both in and out of the home – ensuring both operators and its customers can maximize revenue potential by capturing as much of the consumer excitement as possible.

By this time consumer level AR based smart glasses are anticipated to have hit its inflection point and growth among the user base will accelerate. Smart glasses in particular will help create market forces that push for indoor positioning and location based services. As more individuals perform daily tasks using head-worn wearables companies and operators will increasingly reevaluate how they operate with advertising, content,

and services to better target these devices. 5G will serve as a key enabler and facilitator for these types of services, to ensure operators and companies offer end users the best possible experience. More advanced types of content (e.g. video with translational movement) and a growing number of connected devices on a person (e.g. smartphone, smart glasses, smart watch, etc.) will place increasing demands on mobile networks, particularly during peak daylight hours in congested and populous areas.

Some of the advanced content will rely on cloud servers to mitigate growing demands on bandwidth and local processing. Hybrid cloud services will provide the necessary bridge towards more pure cloud based services, which are expected to start appearing during this period of time. By shifting the user experience to the cloud it becomes possible to produce “thin form” HMDs (primarily display and sensors) at a low cost to display the cloud content. Services and platforms would become relatively hardware agnostic and consumers will have relatively consistent experiences across devices (largely dependent on quality of data services).

2.4. Cloud VR and MR

The last stage discussed in this white paper occurs during the pivotal 5-10 years from the early stages when both AR and VR are expected to experience the largest growth potential. This potential is generated by multiple technological advancements including: 5G, cloud based services, and potential hardware advancements like displays that can transition between opaque (for VR) and translucent (for AR).

This stage has the most technological uncertainties. For example new displays that satisfy both AR and VR applications have the potential to enter the market by this time, but technical issues could hold it back. While VR HMDs that include video pass-through can enable AR experiences the bulkiness of the display will preclude most users from using these devices in public (outside of location based VR services). The combination of VR and AR provides users with the widest breadth of content and services and fulfills many of the grandest visions of future AR/VR market applications.

Display resolutions and highly immersive content will also play a key role in pushing users to seek out more robust data services and plans. FOV could range from 1080*1200 per eye to a retina VR display (6600 x 600) per eye and require data rates at the low end (30 FPS) between 100 Mbps to 9.4 Gbps at the high end (120 FPS). There are of course a range of factors like hybrid cloud rendering and foveated rendering which could help manage bandwidth requirements, but regardless the bandwidth demands for many applications in this stage will outstrip what is possible with current mobile networks.

Motion to photon latency, the time from head movement to display update, is always a concern and here too next generation networks like 5G will best serve consumers who use their devices in a wider range of locations or on the move – 5G network latencies near the edge are expected to range from 1ms – 4ms, which is significantly less than 4G networks which often carry latencies in the tens of milliseconds (VR is optimal at total latencies under 20ms). By 2025 the use cases for AR/VR will extend across many users' daily lives and its growth will not occur in a vacuum - other transformative shifts like autonomous vehicles will create more touch points for users to partake in AR/VR applications and supporting these types of devices over greater distances in traffic is another prime use case example for 5G.

To get from Stage 0 to Stage 4, a great deal of milestones must be satisfied and network connectivity is perhaps the most critical if AR/VR is to live up to its billing as the next great compute platform and to enable cloud AR/VR. Currently 5G stands as the best solution to meet the broadest range of needs for AR/VR and across the widest breadth of users and enterprises.

2.5. 5G as a Driver of AR / VR

First and foremost 5G is expected to offer high coverage and capacity to boost speeds and reduce latency dramatically, all of which is critical for AR and VR applications. The prospect of lower data transmission costs is perceived to be an added advantage of 5G. There is a significant overlap between the requirements of AR/VR and the capabilities and functionality that 5G promises, especially with respect to the speed and latency benefits. Hence, 5G is a key business driver for the long term development of AR/VR.

The current 4G/LTE networks and its proposed successor, LTE Advanced Pro, are expected to be largely unable to offer a uniform user experience for many AR/VR applications particularly as the market evolves and develops in the latter two stages. In such a scenario, the market will be unable to establish a credible business case to support the more advanced pervasive use cases of AR/VR technologies. 5G is a game changer and it provides solid justification for the existence and evolution of these applications. AR and VR is anticipated to transform the way markets operate globally, and 5G should make that transformation possible.

AR and VR could soon stretch connectivity limits on current 4G/LTE networks. Although 1 Gbps throughput may indeed be possible with LTE Advanced- Pro, some applications will demand even higher speeds to deliver the intended experience. Moreover, present levels of latency would render the AR/VR experience somewhat disappointing to unusable in most advanced cloud-centric cases. 5G, which is scheduled for rollout in 2020, is seen widely by Wireless X Labs and ABI Research as the key to unlocking the potentially vast market opportunities available in this area. The success of these opportunities will depend on the reliability, low-latency and uniformity of the mobile and fixed- wireless broadband infrastructure, and its ability to deliver the ultra-high speed and capacity needs of AR / VR. In terms of latency targets for 5G, it is expected to be as low as 1 ms, allowing the AR/VR imagery projected to users to refresh and adjust immediately as users move their head, even with minute changes in their field of vision or angle of viewing.

5G should offer:

- 20 Gbps peak data rates, using a New Radio (NR) air interface while consolidating licensed, unlicensed, shared spectrum and previous generation technologies into a single connectivity platform.
- Substantially reinforced capacity and coverage to support up to 1 million devices per km2
- Even at the cell edge, 100 Mbps data throughput will be assured – while data rates for retina VR are higher, the use of hybrid cloud computing, some light levels of compression, foveated rendering could help to enable lower data rates to be seamless with a cloud VR architecture. This will ensure that the user experience remains at high levels and that cellular systems appear as if they have no areas of poor coverage. The discussion to enable this is currently focused on the decoupling of the uplink and downlink, so that lower frequency (thus better coverage) is used for the uplink, which is somewhat constrained by the end user device's transmission capabilities
- 1 TB/s/km2 area capacity, to cater for a much denser subscriber base, especially in busy densely populated urban areas.
- 1 ms over-the-air latency to enable near-real-time use cases, including autonomous driving, AR/VR, remote operation of specialized equipment and other use cases that are yet to be envisioned

This enhances current 4G capabilities with a 10X increase in throughput, 10X decrease in latency, and 100X increase in traffic capacity. 5G will not only improve, but will also become a necessity for some of the most innovative and advanced AR and VR applications.

2.5.1. Expected KPIs of 5G

Therefore, 5G potentially offers a number attractive features, particularly high reliability and stability along with greater security in connectivity. This heightened security feature is growing in importance and is one of the most cited critical factors for new technologies. Considering current market forecasts for 5G deployments and rollouts Wireless X Labs and ABI Research expect 5G enabled VR devices to start shipping in larger numbers by 2021. If network rollouts and service plans enter the market sooner these penetration rates would reciprocate and move up in the timeline.

The carrier serviceable addressable market (SAM) opportunity in AR/VR is significant and by 2025 is expected to reach more than $93 billion, roughly 30% of the total value of AR & VR opportunities.

Connectivity includes mobile data plans and fixed cellular data services (for in-home Wi-Fi) across AR an VR – depending on how and when 5G is deployed this segment of the SAM could almost double if strategies are accelerated or more aggressively marketed.

Content and platform revenue depend greatly on service launches, content agreements, and activity within the space – some mobile operators like Sky, Verizon, SK Telecom, and MTG have begun activity across both the content and platform segments for VR and AR. Content and platforms include cloud computing, value-added services (e.g. conferencing, storage, etc.) across consumer and commercial/ enterprise. Services and content could include: customer support, see-what-I-see, training, remote monitoring, visualization and design.

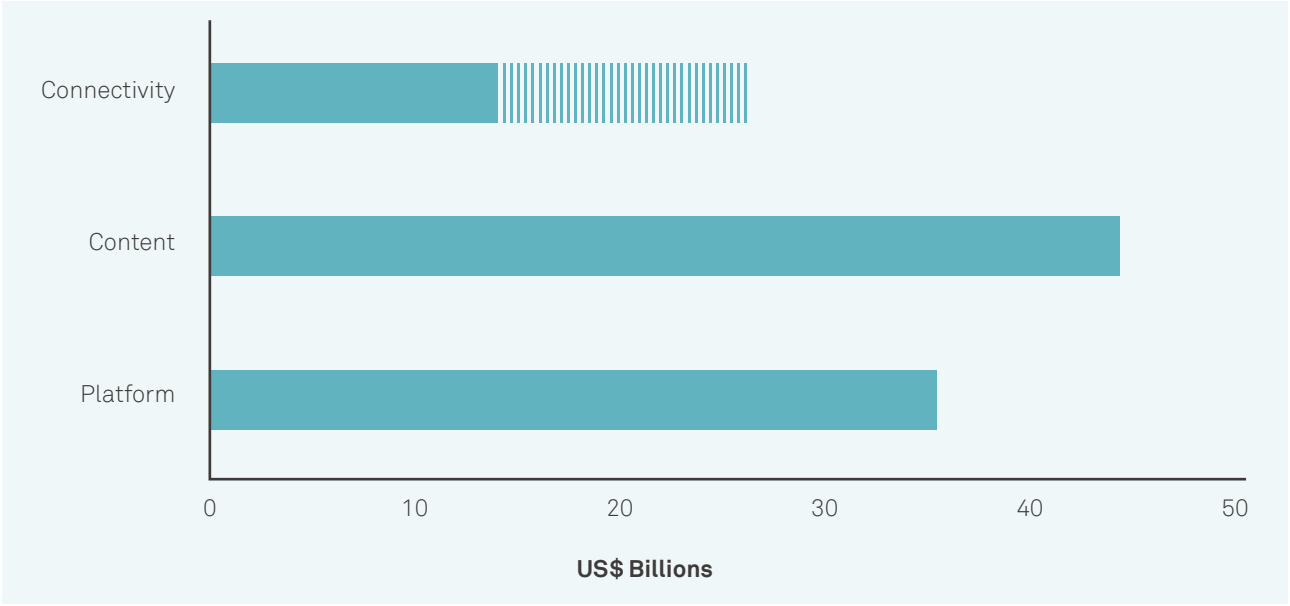


Chart 5: Carrier Addressable Opportunity in AR/VR World Market, 2025
(Source: Wireless X Labs, ABI Research)

In the next section, a summary will be provided on how 5G can be a transformative force in the AR/VR market:

2.5.1.1. Video and capacity

AR and VR devices depend extensively on the state and versatility of video technology, which requires high bandwidth and this will certainly increase in line with the advancing requirements of AR and VR applications. With the emergence and evolution of new video formats, such as 360° video, progressively higher bandwidth will be required. At present, 4G handles 360° video at 4K 30 fps (frames per second), but 5G is expected to improve this standard by handling the video experience at 8K 90 fps (higher resolutions and frame rates are possible with hybrid cloud computing and foveated rendering). Users would therefore stand to benefit from a richer video experience.

2.5.1.2. Network speeds

AR and VR applications will soon exceed the Gbps (Gigabits per second) limit of 4G networks as they become more sophisticated in nature. With 5G's capacity-enhancing mobile broadband, higher frequency bands will be available for applications to run on, and a new radio standard known as 5G New Radio (NR) is in final stages of development. This should potentially increase 5G network speeds to tens of Gbps to support the speed requirements of AR/VR applications, providing a more uniform experience for users of AR/VR given the ultra-high data volume requirements that can be handled more effectively

2.5.1.3. Latency

In addition to the concerns over motion to photon latency, AR and VR applications span online gaming, documentaries, entertainment and sports, extending latency concerns to more than the VR element alone. In online gaming, for example, it may mean the difference between “shooting the opponent” or “being shot by the opponent”. Ultra-low latency levels associated with 5G are expected to smooth out and accelerate the processing and to deliver a much crisper, more powerful and real time experience to users.

2.5.1.4. Uniform and stable experience

With AR/VR becoming more sophisticated, attaining a consistent and reliable user experience from existing connectivity standards can be a challenge. AR and VR users will undoubtedly need a constant, strong and stable signal. Any lingering latency or drops in service could otherwise significantly jeopardize the AR /VR users' experience. 5G's aim of overcoming this challenge is to provide a consolidated network and to use multiple antennas (small cells) to ensure coverage for the user. This should potentially benefit those even at the network's edges.

2.5.1.5. Higher energy efficiency

Finally, 5G will reduce power consumption while allowing more devices to access and consume enormous amounts of data at super-fast speeds via mobile and fixed wireless broadband. It is estimated that the value of energy efficiency for 5G will be a 90% improvement over existing LTE networks, driven by ultra-lean designs in base station setup, advanced beamforming techniques, separation of user-data and system control planes on radio interfaces, virtualized network functionality and cloud technologies, to name a few factors. Stronger and stable network coverage should also facilitate signal detection / retention, resulting in longer battery life for devices.

Business Opportunities for MNOs

Having discussed the technological evolution of AR and VR, along with the changes to services and content as the market builds toward a more pervasive compute environment (via 5G and cloud AR/VR), there are many opportunities for MNOs and other operators to target during each of the aforementioned stages.

3.1. Content, Services, and Business Models

AR and VR in the early stages have targeted different segments of the population; after early entrants like Google Glass failed to garner traction amongst consumers, AR found traction with commercial and enterprise applications while VR is most associated with consumers. VR, however, has strong potential in the commercial and enterprise space with Wireless X Labs and ABI Research expecting this facet of the market to comprise over 46% of total revenues and nearly 55% of VR HMD shipments by 2025 (up from 26% and 41% respectively in 2016). Similarly consumer grade AR smart glasses are expected to gain momentum in the coming years as product pricing and form factor become more amenable to consumer tastes and preferences.

Outside of tethered VR and the limited standalone units most VR experiences have been seated or standing without translational movement (also referred to as 3DOF – three degrees of freedom). The addition of translational movement (e.g. standing and squatting, moving forward and back, left and right) greatly enhances the level of immersion, providing for a more natural experience.

3.1.1. VR

The VR market today is weighted heavily in the gaming and video/advertising segments. Sponsorships and VR experiences intended to promote other premium content/events have predominated in the video market, although select experiences like sporting (e.g. Intel True VR) and live events (e.g. NextVR) have helped VR rise above these more mundane short form experiences. Telcos and pay TV/broadband operators have also started exploring VR opportunities:

- BT introduced 360ºsports content
- MTG launched a VR platform (Viareal)
- Meo created a VR service as part of its multiscreen TV offering (used Samsung Gear VR)
- Orange released a mobile reliant HMD (priced at EUR 50) for Android and iOS smartphones to support its Orange VR 360 application.
- SK Telecom unveiled its “360 Adaptive VR Live Streaming Platform” at MWC 2017. The operator is planning to show 360º views in the upcoming 2018 Winter Olympics.
- Korea Telecom will similarly demonstrate VR at the 2018 Winter Olympics, showcasing its 5G technology.
- Telia has demonstrated a live VR sporting event production, collaborating with Nokia to leverage its Multi-access Edge Computing platform.
- Sky has both trialed VR services and has launched a VR app, “Sky VR”

Similarly mobile working groups like 5GMF (Fifth Generation Mobile Communications Forum) out of Japan and Korea's 5G Forum have both cited AR/VR as key uses cases and business opportunities for 5G networks. AR/VR was listed among 13 key 5G use cases, while the 5G Forum counted AR/VR among the five major business opportunities for 5G. Before these networks launch and become more widespread, VR content in particular will undergo years of development and maturation.

The VR gaming market for instance, like 360 video, is suited towards shorter or more limited experiences than is typically found in the core gaming and OTT viewing segments. In all cases, there remains a learning curve for content creators to best create immersive VR experiences and some early limitations on consumers' willingness to wear the HMDs for prolonged periods of time (typically most VR sessions are 20 minutes or less).

While less prolific, the commercial and enterprise space for VR technology has generated some initial momentum. Healthcare companies like Surgical Theater are helping surgeons to better prepare for surgeries while others target training and treatments (e.g. anxiety and PTSD). Other activities within the healthcare sector include:

- Cedars-Sinai Hospital in Los Angeles introduced VR to help patients relieve pain and stress. Content includes virtual visits to beautiful landscapes, swimming with whales, and art studios.
- Similar dental pain management studies have been published in academic journals; coastal scene content provides improved pain relief compared to urban settings.
- MindMaze has received FDA approval for stroke recovery.
- Give Vision helps individuals with vision impairments using a mobile based HMD.

The largest auto manufacturers and dealers are experimenting with virtual showrooms and VR experiences to boost interest in vehicles and brands and real estate companies are similarly giving virtual tours to prospective international clients (e.g. China based ConductorVR's VRoom). Virtual tourism also enables participants to experience remote and exotic locations or pre-visit destinations before buying airline tickets and vacation packages. Additional examples include:

- West Texas-based Betenbough Homes has been able to use VR systems to offer potential buyers a virtual tour of their properties, as well as to allow them to try out a number of interior design options to personalize their homes before placing a firm order.
- Self-service tools such as Yulio allow architects to display models to multiple headsets to enhance customer exploration of 3D architectural designs.

In the retail space, companies have used VR in both the B2B and B2C space – Walmart for example has started using VR for training (estimated 140,000 employees will benefit from program developed by STRIVR) while Baidu launched a virtual storefront in VR. Companies like Kantar Retail and InContext Solutions use VR to offer clients the ability to test market store layouts, shelving, etc. in virtual environments before going live or conducting more expensive or labor intensive mock-ups. VR hardware providers and retailers have also formed partnerships to demonstrate products, services and conduct marketing campaigns through in-store displays/demos or via apps.

Location based VR has expanded to multiple locations and across all regions, although traction is strongest in North America, Asia-Pacific, and Western Europe. Revenues at these locations are more consistent with fees typically charged per session or time period. Installations include dedicated VR entertainment centers, VR arcades, and the use of VR in public venues. Theaters, like IMAX in the US, have added VR arcades to complement existing revenue streams and to attract new customers. In addition VR has been added to public transportation services like French Railways SNCF (adopted SkyLights VR HMDs) and European high-speed railway Eurostar. Public transportation in general is a prime target for AR/VR and could significantly benefit from next generation mobile network services to accommodate higher data consumption and need for persistent connectivity across extended distances.

Activity in the government, military, and security sectors have also contributed to the early traction in the market, examples noted below:

- The U.S. military is progressively using VR to simulate combat jumps as part of its parachute training for its special forces divisions, which practice the jump in a simulated mission environment to attain higher levels of preparedness and then proceed to do the real jump.
- Visualize developed a set of four VR training videos to help the British military in recruitment efforts.
- Lockheed Martin is saving up to US$10 million annually by using 3D imaging in VR systems for design visualization and maintenance training in its production line.

The potential for immersive experience to accentuate the learning process has also generated attention within educational institutions as well. Early trials have stretched from higher learning (e.g. universities and post graduate training) to lower grade levels to help enrich coursework and elicit stronger interest from students. Some examples to date include:

- Singapore's Ministry of Education is taking advantage of VR systems to offer students a virtual excursion to international destinations, with a virtual guide covering the educational aspects of the tour.
- Case Western Reserve University is starting to use VR for anatomy dissections from 2019, deducing cost, while increasing flexibility, and addressing ethics within medical training.

3.1.2. AR

The AR smart glasses market has almost exclusively targeted the commercial and industrial space, serving roles like pick-and-pack (and related inventory/ operations applications), see what I see, and training – examples below:

- A DHL test of an AR application in its warehouse resulted in 25% efficiency improvement in the packing process.
- Airbus's MR application in production reduces checking time of brackets in fuselage from 300 hours to 60 hours.
- Boeing AR training results were 30% faster and 90% more accurate on the first tries of trainees.
- First responders and health professionals have instituted AR trials for see what I see, training, and providing additional visual information to health professionals (e.g. additional camera feeds, vitals, etc.). Smart glasses are also used to help individuals who are visually impaired (e.g. eSight, NuEyes, OrCam, OxSight, etc.) both navigate and see everyday objects.

AR viewed with a broader lens has had tremendous successes in the mobile space like Pokemon Go and retailers (e.g. Lowes) are starting to release AR apps to help consumers visualize furniture pieces in their homes. Apple also released its ARKit for developers, which will fuel additional investment and interest in AR (and likely VR) across a wider spectrum of verticals and market applications. Companies that have pioneered

the VR space, such as Facebook and Samsung, are actively targeting the AR market. While the spread of mixed reality applications awaits hardware deployments in these early stages the arrival of MR HMDs will start to convergence between AR and VR which will continue throughout the stages depicted in this white paper.

3.1.3. Business Models

In the video space, most 360º video has been promotional in nature or used minimal advertising – again most users only use VR for comparatively short viewing sessions. Service providers have also used VR and 360º as a means to differentiate services (e.g. Sky's VR App with 20+ pieces of 360º video content) and reduce churn, but in most cases these are complementary features and not quite yet standalone packages. As the market moves out of the early stages and into Stage 2, the market will start to see more premium content (both subscription and PPV/TVOD).

Those applications that are currently more experimental in nature will also start to mature and the associated ROI of these campaigns and applications will start to become clearer. The gaming market has followed traditional pricing models (pay per title) but new virtual worlds/spaces will enable other pricing models like subscription and free-to-play/virtual goods.

Outside of the consumer based gaming and video markets the commercial and enterprise have started to deploy VR and AR solutions into the market with pricing typically on a per user/HMD monthly rate or annual packages. Retailers like Baidu have started to sell goods in VR spaces but the virtual marketspace is still very nascent.

3.2. Transition to Latter Stages

Both premium pricing models (PPV, EST, TVOD, SVOD) and advertising will make significant strides during this stage. Further launches and rollouts of 360 video services will begin filling the content void – live events like sports and concerts in particular will provide users with differentiated experiences (e.g. multiple viewing angles, immersive experiences, additional content like stats). Advertising in 360 video will continue to evolve beyond pre-existing 2D ads in virtual spaces and leverage more interactive features such as "choose your own path."

While it is possible for the ecommerce space to push more VR shopping experiences Wireless X Labs and ABI Research believe the subsequent stages are more likely targets for retailers. A great deal of effort and cost will go into virtualizing products for the VR shopping experience and this investment is better placed in the latter stages. Consumer based AR (both smart glasses and mobile), however, will play a critical role in this stage for retailers to leverage location based advertising, indoor positioning, and related technologies to provide better customer service and individualized shopping experiences (e.g. helping customers navigate stores to find objects on their shopping lists). Retailers are already experimenting with the convergence of ecommerce markets and physical brick and mortar stores and the spread of AR will further meld one's digital profile with multiple facets of the user's shopping experience.

3.3. Latter Stages of Cloud AR/VR

Stage 3 represents an opportunity for operators (mobile in particular) to package hardware with service tiers that best fit usage habits of the end user. For some individuals, maximum data rates and minimal latency will best serve their needs for VR content on the go, while others (e.g. AR users) could benefit from a seamless and consistent connected experience and could take advantage of an operator's efforts in fixed-mobile convergence (FMC). Introducing next generation mobile network features could also accelerate the adoption of AR and VR, particularly if consumers begin to encounter these devices in increasing number in public (e.g. public transportation) and workplace.

VR content distribution (video and gaming) at this stage is likely to still predominantly favor incumbents, but opportunities for mobile operators (region dependent) will start to open up and will carry over into the critical fourth stage.

AR applications will further extend to a wider range of businesses and retailers allowing operators to offer business customers new services and features. See what I see and remote control applications for example will benefit heavily from reliable and low latency service, allowing operators to charge a premium for these features. The use of the cloud will be in full swing by these latter stages, placing a premium on the pervasiveness and continuity of connectivity – factors that have often limited the always connected user experience and 5G is anticipated to help bring this use case to fruition.

Summary and key take-aways

The market potential for AR and VR is just starting to unfold and while uncertainty exists with any nascent market there is already tremendous support across industry players. Consumers will increasingly embrace AR and VR applications and as trials become deployments within the commercial and enterprise sectors these technologies will begin to yield both economic and social benefits.

4.1. AR/VR – Economic and Social Benefits

AR/VR coupled with the emergence of 5G will offer several key economic and social benefits that fall in three key categories: Access/Accessibility & Communications, Efficiency/Productivity, and Context/ Immersion.

4.1.1. Access/Accessibility & Communications

From see-what-I-see applications to virtual tourism AR/VR has the potential to dramatically close the distance between people and regions. Telehealth for example helps expands the reach of medical professionals to more remote urban areas that might otherwise lack access to specialists, regular follow-ups and appointments. VR has also found applications in mental health and supporting public initiatives such as the prevention of drunk driving – in this specific application VR HMDs have been used to simulate a drunken state to help individuals gain a better understanding of impairment and how activities like driving can become compromised.

AR, both smartphone based and smart glasses, will also connect users to professionals in everyday task, be it professional advice or on the job training. Contractors or tradesman could provide remote service in pseudo do-it-yourself fixes, providing easy to follow digital overlays over pipes, electrical outlets, etc. In the workplace on-site training or consultations can take place without the added transportation costs of flying in specialists. In many regards communication will become more ubiquitous and occur at a much deeper level.

Consumers for instance could meet with professionals in a virtual setting to discuss banking, legal matters, financial planning, etc. without travel delays and associated costs. 5G is well positioned to accommodate the additional demands this richer form of communication will engender as more users embrace these technologies.

4.1.2. Efficiency/Productivity

For professionals working in design or creatives, the use of AR and VR could greatly reduce the need for physical modelling and testing, thereby accelerating time to market. Bringing the "computer" in front of the user's eyes at all times dramatically alters the potential use cases and ultimately the willingness of users to embrace new software and services.

In an enterprise context, bringing just-in-time information to employees has been shown to reduce training time and improve accuracy, enabling more dynamic workforce and application of employees into a wider array of tasks, reducing cost and training time for new employees.

4.1.3. Context/Immersion

The barriers between communication will continue to fall but the added presence afforded by AR and VR will make messaging more effective and the content significantly more impactful. It's one thing to read or see a message or call for aid but to experience an event first hand (e.g. a rally or viewing an area devastated by natural disaster) it helps internalize the messaging and makes individuals more likely to act.

As a tool AR/VR will contend as the next compute platform and technologies like 5G will serve as the conduit that helps realize its utmost potential. While the timeline for AR/VR will move slowly and require many years of working through technical barriers, preparation and conditioning is similarly needed in order to reach the finish line and investments today will help ensure companies and operators remain within the lead pack instead of trailing behind.

4.2. Summary

As a potential compute platform AR/VR will serve a role well beyond the immersive content markets, and it will certainly impact both the consumer and commercial/enterprise spaces. The speed of market progression is heavily dependent on continued healthy investment into the AR/VR market but equally importantly the deployment of next generation 5G networks to serve

as the backbone that enables the vast array of future AR/VR applications. While Wireless X Labs and ABI Research view the AR/VR market as a long term proposition it is not constrained by any immutable limiting factors, so the market could certainly accelerate beyond what is currently projected.

To reach the markets fullest potential several milestones were discussed in this white paper and are highlighted again below:

- Lower priced solutions - the market is already heading this way and new products like cloud-based, or thin client, HMDs will further reduce pricing
- Higher screen resolution – in part an element of the smartphone market (mobile HMDs) but overall the market is progressing to 4K and 8K screens
- Form factor – in addition to price, AR smart glasses were limited by form factor. Once these devices become more closely matched to traditional eyewear the consumer market will begin to take shape. If new technologies like light field displays and/or transparent OLED displays allow for more common form factors between AR and VR the market should begin to converge and bring additional value with each HMD, progressing toward mixed reality.
- Network – most of the technological advances in AR and VR will add additional data requirements and demands on continuity of service (this is in addition to the constant need to limit latency). 5G is primed to satisfy these needs while presenting operators with new revenue and service opportunities.
- Content – the library of content and applications will continue to grow, but the rate and breadth of supported use cases will be highly dependent on the aforementioned technological factors. In other words the limiting factor will not be the imagination but available technology.

Wireless X Labs is a brand-new platform designed to get together telecom operators, technical vendors and partners from vertical sectors to explore future mobile application scenarios, drive business and technical innovations and build an open ecosystem. Wireless X Labs have set up three laboratories, which aim to explore three major areas: people-to-people connectivity, applications for vertical sectors and applications in household.

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