HUAWEI

AR Insight and Application Practice White Paper

STRATEGY ANALYTICS
Celebrating 25 Years of Insights

Virtual and Augmented Reality

Contents

Executive Summary

- **Industry Trend:**
  - AR overlays digital objects and information on the real world.
  - Although dedicated AR headsets have arrived, most consumers today experience AR on the smartphone.
  - The real benefits from AR are when the user is mobile. This makes AR a perfect match for mobile networks.

- **AR Device:**
  - AR apps have been popular on smartphones for some time. Smartphone-tethered AR headsets will become the dominant form factor. By 2026, sub-$500 headsets will dominate as AR headsets become mass market. And the market will grow explosively. By 2026 we expect over 53M units to ship, generating over $30B revenues.
  - Dedicated AR headsets are largely an enterprise market today. It is characterised by high price points and low volume. The hands-free nature of dedicated headsets allows workers to perform tasks assisted by AR.

- **AR Use Cases:**
  - The top two use cases today are social & communication apps, and AR games. AR has already been integrated across all app categories, including innovations in education, retail, navigation, and health & fitness.
  - In the future, we expect that navigation will underpin other AR experiences, such as co-located gaming.

AR Platform:

- Apple's ARKit and Google's ARCore are tools for on-device app development, with each addressing only their own OS; Huawei's AR Engine and tools are more fully featured with additional functionality for hand and full body motion tracking, and are the first to introduce and massively commercialize features like multi-object modelling.

- Although processing is mostly done on the device today, in the future, AR will integrate devices, the edge, and cloud. Global map data and global user information are naturally suited to the cloud, whereas accurate positioning and posture determination, local map data, and rendering of certain 3D scenes are suitable for edge computing. High-bandwidth, low-latency 5G networks will play a prominent role in AR with device-edge-cloud integration.

Network Enabling:

- Guaranteed Bit Rates, Latency, Accurate Positioning and Mobility as key network aspects which will impact AR, Edge computing and storage is essential to deliver the full benefits of AR.

- Network slicing can be a cost-effective way to deliver guaranteed QoS for AR.

Ecosystem:

- AR is not only about the device, the content, or the network. It is about combining the capabilities of all three to create a compelling offering. A partnership approach, establishing unified standards and mechanisms, and bringing together expertise across all of the different areas, will create a prosperous AR industry.

02

AR Insights & Industry Trends

2.1 AR Market Today and Tomorrow

Augmented Reality (AR) is a technology that overlays data (including text, images, videos and 3D models) on top of a user's view of the real world. Sensors and machine learning techniques enable mapping of the external environment and detection of real-world objects to provide useful functionality.

Virtual Reality | **Augmented Reality**

- Isolated from the real world
- Tourism example: Remotely explore a virtual recreation of an historic site

- Contextual information overlaid on real world
- Tourism example: be guided through a real-world historic site

Figure 1: VR versus AR (Source: Strategy Analytics)

What differentiates AR from VR? VR is a completely immersive technology with the user's vision filled by a virtual environment. This makes it inherently immobile – the user would rather be in a safe environment and moving only a very limited distance to avoid bumping into walls or other objects, or falling over. Because AR overlays digital objects and information on the real world, the real benefits from AR are when the user is mobile. Perhaps they need additional information on an unfamiliar environment or are guided by AR navigation to a destination. This makes AR a perfect match for mobile networks.

Today, although dedicated AR headsets have arrived, most consumers experience AR on the smartphone. A combination of a live camera feed with an AR overlay shows the augmented world on the smartphone screen. Over 95% of high-end smartphones today can support this functionality.

Dedicated devices, typically costing $3,000 for the high-end headsets with transparent stereoscopic lenses, remain outside of consumer price points. However, they are delivering value in enterprise sectors such as healthcare, heavy industry, and logistics. The hands-free nature of such devices allows them to address many use cases which smartphone AR cannot, and which provide greater value for their use in a work environment.

2.2 Key Questions

This report aims to answer some key questions to help companies across the value chain play a role in the future of augmented reality.

- What are the devices like today and how will they change?
- What will be the features of the leading devices?
- What is the size of the market opportunity?
- What key use cases exist in the consumer and enterprise sectors?
- How will those use cases evolve?
- What are the key development tools for AR, and what experiences will they enable?
- What network features of 5G will make the most of these opportunities?
- What challenges will be faced, and what strategies will overcome them?
- How can AR providers map the landscape of use cases, development tools, network capabilities and hardware together to create a roadmap for success?

03

AR Devices

Today, there are many different types of AR devices. Some are more advanced than others, allowing them to address different use cases. But for those more advanced devices not only is the cost higher, but also the weight, which limits design choices (making it more difficult to design something appealing to the consumer) and makes them unsuitable for some work environments.

- **Binocular –** with a transparent binocular display, allowing for 3D stereoscopic images, these can address any use case. Standalone devices such as the HoloLens and Magic Leap are some of the most advanced (and expensive) devices on the market today. More recently, lighter and cheaper smartphone-tethered binocular devices have come to the market, such as the Nreal Light.
- **Monocular –** typically not using a transparent display, these types of AR glasses are suitable for simple use cases such as notifications or simple navigation. They are usually a standalone device. Examples include Google Glass (aimed at the enterprise market) and Solos (AR cycling glasses).
- **Slot-in –** with a smartphone slotted into a frame, these type of glasses either use the smartphone in a horizonal position with a downward-facing screen reflected in a semi-transparent mirror, or use the smartphone screen much like a simple slot-in VR headset (such as the Samsung Gear VR), but using the smartphone camera for "pass through" video. The single successful example of this form factor was the Lenovo Star Wars device.
- **Contact Lens –** AR contact lenses might seem like a fantasy future technology, but they are available today. Mojo Vision's AR contact lenses are medical devices designed to improve the perception of visually impaired users and are undergoing clinical trials. Several tech companies also have patents (such as Google and Sony) but are yet to launch such a device.
- **Static Holographic Displays –** holographic displays have some AR functionality for particular use cases. Examples include the static desktop display from Sony and an add-on smartphone screen from IKIN.
- **In-car AR –** heads up displays (HUDs) inside cars are becoming increasingly commonplace. Many manufacturers such as BMW and Hyundai are integrating HUDs into the vehicle, and consumers can also buy their own HUDs from suppliers such as Garmin.

Different technologies are found in the various devices. The image below shows all of the different components in a fully featured binocular AR device.

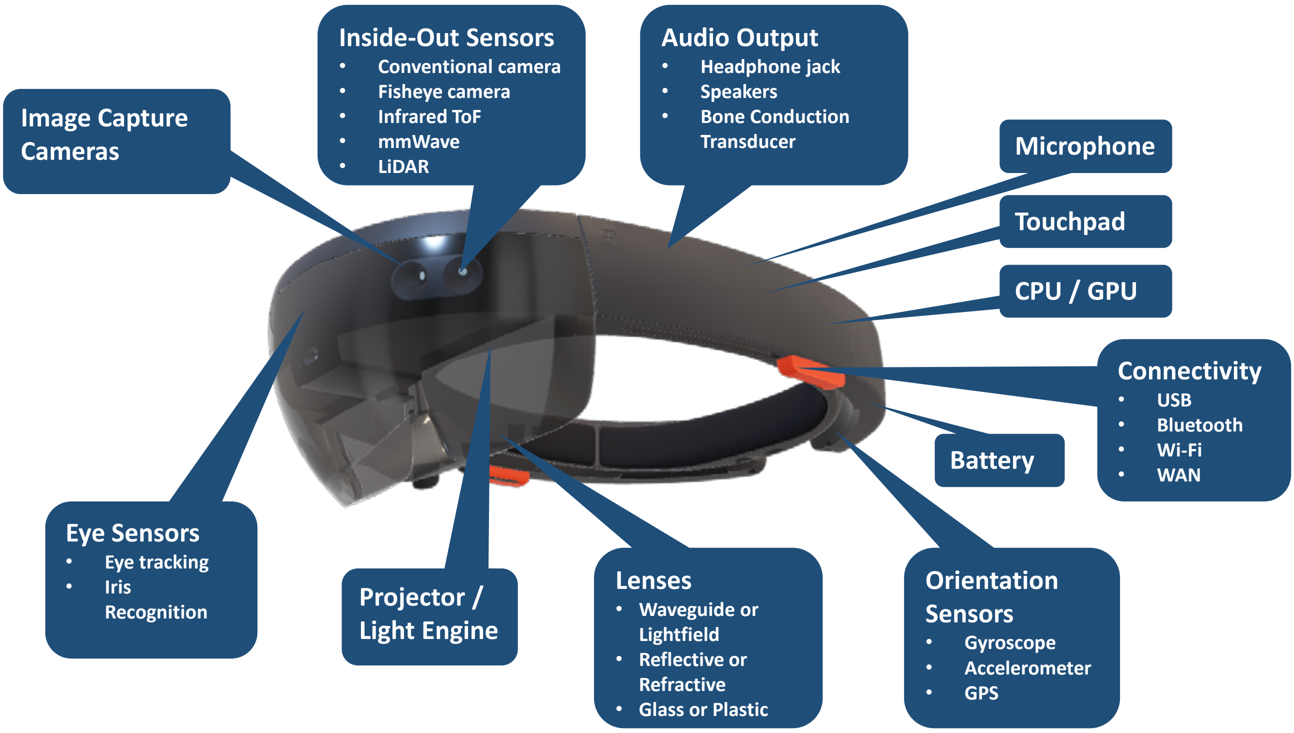

Figure 2: AR Glasses Components (Source: Strategy Analytics)

The main feature of AR is of course the lens technology. A fully featured device will include transparent binocular lenses and be able to show stereoscopic 3D objects as if they were present in the real world. This type of lens is cutting edge technology and is one of the most expensive components of high-end AR devices.

Simpler devices might feature transparent low-resolution displays, useful for overlaying data to the real world or providing notifications, but otherwise limiting the use cases. The simplest devices have displays which are not transparent, but do provide relevant context-sensitive information based on objects around the user.

One challenge with any type of lens technology is making it compatible with prescription corrective lenses. Today this challenge is usually overcome by designing the headset so that it can be worn in front of, or in the case of simpler devices clipped on to, conventional spectacles. In future, AR displays might be integrated into prescription lenses.

In order to overlay contextual information, the device must also understand the world around it. This means incorporating positioning and visual recognition technology. External facing sensors such as cameras and depth perception LiDAR sensors provide data, along with other internal sensors such as GPS modules and gyroscopes. Some simpler devices use QR code readers, suitable in a warehouse setting but limited for consumer use cases. The more advanced the sensors, the greater the need for AI to be incorporated to make sense of the data being collected. This functionality might reside in the cloud or on the device.

The user must also be able to control the device as well. It is quite common for AR devices to include integration with a voice assistant. Some use the external sensors to track the user's hand movements to provide gesture control. Even more advanced input mechanisms include gaze sensors to detect what the user is looking at in order to provide contextual information.

Finally, AR devices also usually include some form of connectivity module. Most commonly this is Wi-Fi, although some include 5G modules, or pair with a smartphone either using Bluetooth or a cable.

The sheer number of components means that a completely standalone, fully featured AR device can be very expensive. They are also heavy and bulky, and battery life can be a limiting factor. For example, the HoloLens 2 weighs over half a kilogram, and has a battery life of around 4 hours. It's not really suitable for extended continuous use. With such bulk, it's also not the most fashionable device and would be unlikely to appeal to consumers even if the price point were considerably lower.

One way to reduce the bulk (allowing for improved design choices as well as greater comfort) and the cost is to pair the device with a smartphone. Some of the processing power can be shifted to the paired device, and some of the smartphone components (such as WAN connectivity and GPS) leveraged instead of trying to fit everything onto the headset. An example of such a device is the Nreal Light, a binocular device which manages to achieve a lightweight and appealing design by pairing with a compatible Android smartphone via USB. This is the type of device which we expect will help to build the consumer market for dedicated AR hardware in the near future.

Another approach to creating an appealing and lightweight design is Qualcomm's XR1 AR Smart Viewer reference design. It features a distributed computing architecture. Although the device has its own processor to allow it to act independently, it can also be paired with a smartphone when needed to provide richer experiences.

3.1 AR Device Market Growth

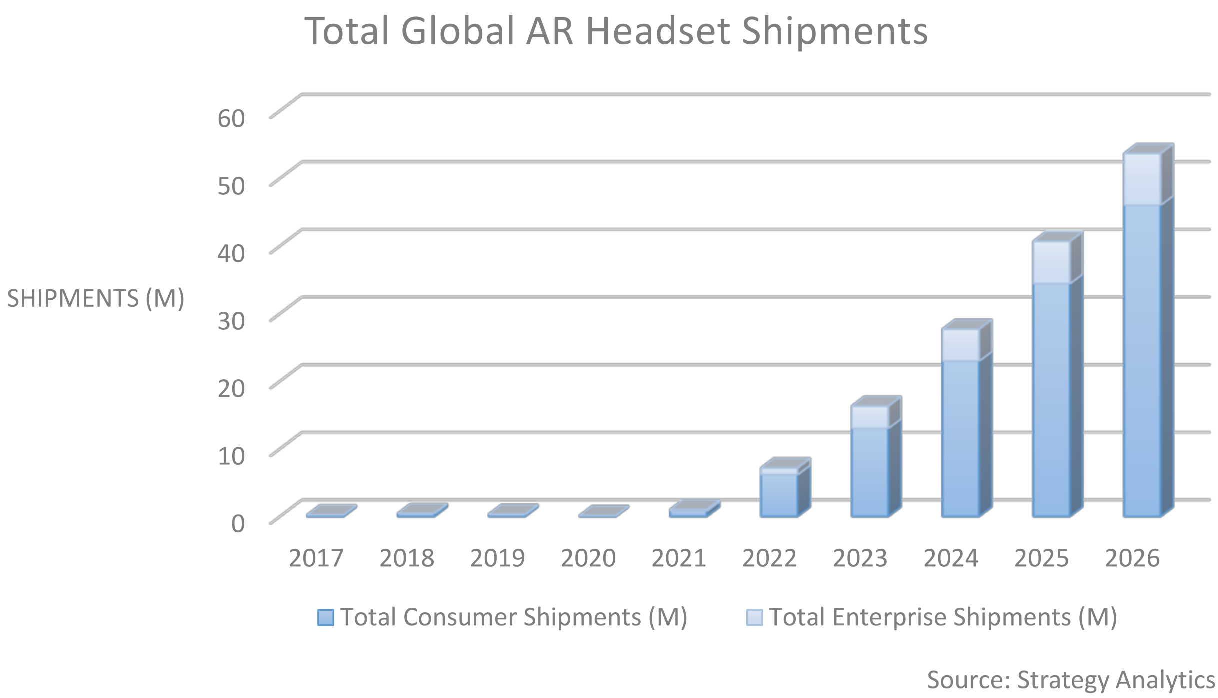

Figure 3: AR Headset Shipment Forecast (Source: Strategy Analytics Dedicated AR Headset Forecast)

Dedicated AR headsets are largely an enterprise market today. It is characterised by high price points and low volume. Although the market has undergone rapid growth over the past few years, this is starting from a very low base. Strategy Analytics data for the year 2020 sizes the market with global shipments of just under 115,000 units, generating revenues of $166M. 81% of headset shipments were to the enterprises.

Once the anticipated consumer headsets arrive, the market will experience explosive growth. By 2026 we expect over 53M units to ship globally, and generate revenues worth over $30 Billion. By that time, we expect the consumer and enterprise market shares to have flipped completely, with 86% of devices shipping to consumers and 14% to enterprise.

In order to reach this market size, headsets will have to come down in price considerably. Early consumer headsets were too high priced to make much of a market impact. The first edition of Google Glass was aimed at consumers but had limited functionality and a price point of $1,500. Magic Leap attempted to entice consumers with a full featured, standalone device retailing at $3,000. More recently, in 2020, Nreal launched its device at a more consumer-friendly price point of just under $600, achieved by reducing the component cost by tethering the device to a smartphone.

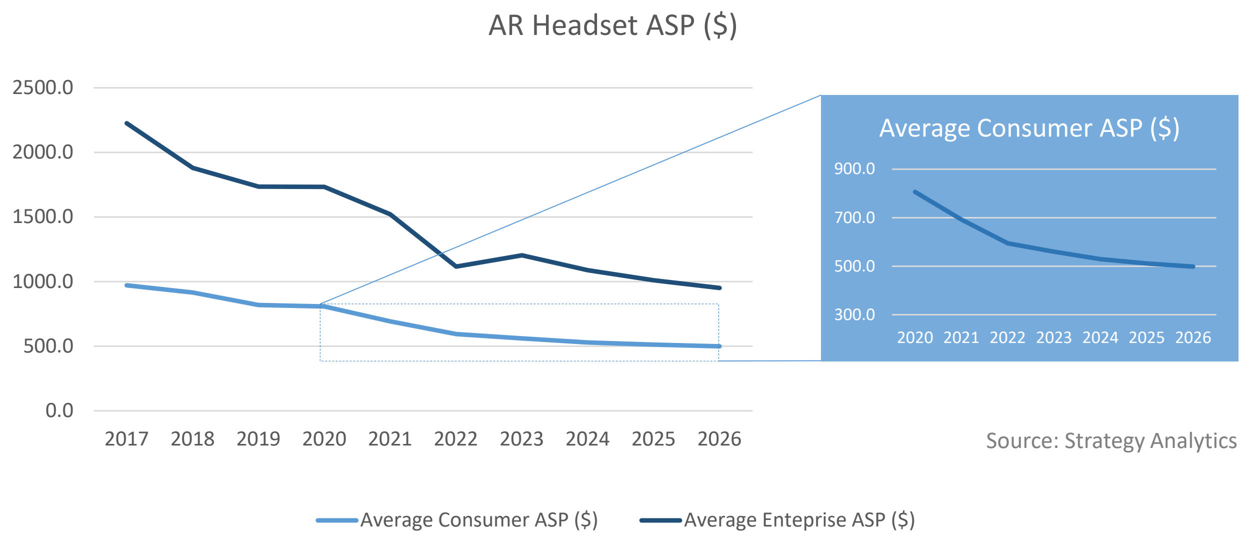

Figure 4: AR Headset ASP (Source: Strategy Analytics Dedicated AR Headset Forecast)

As shown in figure 6, we anticipate further declines in price over time, with the ASP of consumer headsets declining from just over $800 in 2020 down to under $500 in 2026 (a 38% decline). As discussed in the previous section, we anticipate that smartphone-tethered AR headsets, potentially with a distributed computing architecture, will be the dominant form factor, with the reduced cost of such devices relative to standalone AR being a driving factor. We can also anticipate that there will be a range of devices in the market, from “flagship” AR headsets priced close to $1000, to sub-$500 headsets which will ultimately come to dominate as AR headsets become mass market.

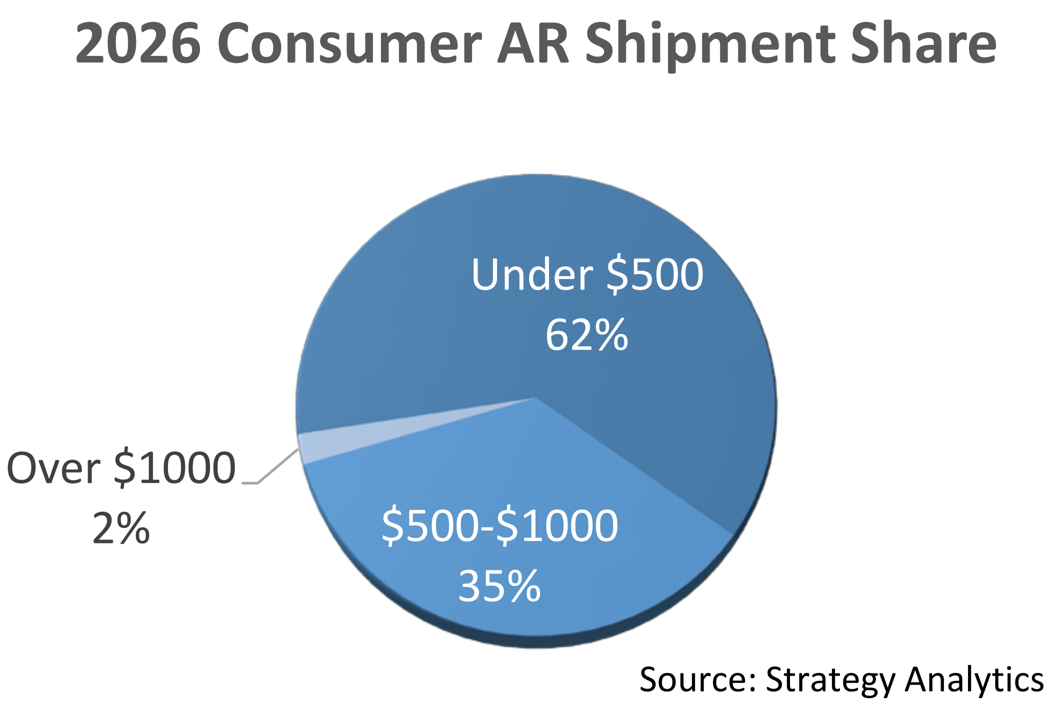

Figure 5: Consumer AR ASP projected 2026 breakdown (Source: Strategy Analytics)

Given that smartphone-tethered devices will be the likely winners, another likely outcome in that scenario is that it is the smartphone OEMs which will dominate the market for these devices. They can provide the tight integration of the two devices, and can bundle the devices as part of their go-to-market strategy. Since mobile operators play a critical role in the distribution of mobile handsets, and can also bundle relevant data plans, this means that carriers will also have a key role to play in the future of AR headsets.

We anticipate that binocular AR devices will be the type most likely to drive the consumer market in the longer term. Displaying 3D stereoscopic images allows this category of AR headset to address all of the possible use cases, increasing the value proposition and utility to the end user. These type of displays also give the “wow factor” that can create consumer buzz and help drive uptake. However, in the short term, simpler devices might help build a consumer market by focusing on particular segments. For example, a monocular device for the health and fitness segment which displays simple navigation information and other data for cyclists and runners. In this scenario, the AR headset market may come to mirror the evolution of the smartwatch market. That market started slowly, and it was the health and fitness applications which really proved the utility of such devices.

04

AR Use Cases

4.1 Consumer Use Cases

4.1.1 AR Today: Smartphone Based

Today, dedicated AR headsets for the consumer are yet to achieve significant market traction. However, supported by developer tools for smartphone OS (including Android ARCore, Apple's ARKit and Huawei's AR Engine), AR has been popular on smartphones for some time.

The top two use cases today are undoubtedly AR lenses used in social and communication apps, and AR games. Consumer AR experiences have been integrated across all app categories. We have highlighted some key innovations in social communication, education, retail, navigation, tourism, health & fitness below.

4.1.2 Social Communication

Social communication is undoubtedly the main use case for AR today. Snapchat has really been the breakout application which has driven AR's popularity. As of 1Q 2021, the company reported 280m daily active users, of whom 200m interact with AR on an average day. Its initial (and most famous) function is to provide AR overlays to the user's face during video calling. It can also provide some level of utility and enhance video calls, for example by allowing users to try out a new hair colour and get their friends' reactions.

Brands, such as L'Oreal, have leveraged these "Lenses" to advertise their products in new and novel ways. Snapchat has enhanced its AR capabilities over time, adding in recognition for other parts of the body, for example feet which allows users to try on virtual shoes. Objects can also be placed in real-world locations. These functions have provided additional novelty to the user experience and also allowed more brands to get involved with innovative AR advertising and marketing.

Snapchat's AR capabilities have been copied by many other popular video calling apps. Facebook's Apple's Facetime incorporates similar functionality. Facebook claimed over 1 billion users of AR chat filters in a 3 year period (across Instagram, Messenger and other products).

Huawei's AR Lens product incorporates "3D CuteMoji" which tracks the user's facial movements and expressions and maps them onto a 3D avatar. The AR Lens appeals to young users. It is one of the most popular functions of Huawei's smartphone apps. TikTok and Apple's FaceTime have also incorporated similar AR functions in their apps. It is primarily through these social communication apps that users today are familiar with AR.

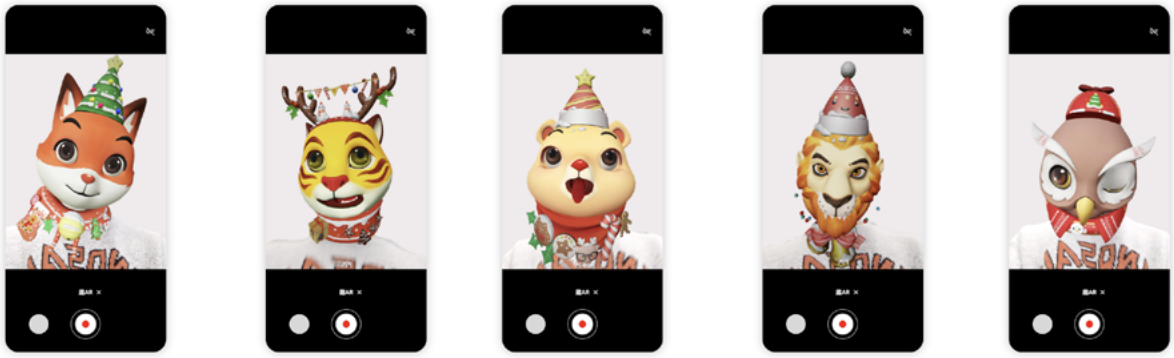

Figure 6: Huawei AR Lens CuteMoji (Source: Huawei)

4.1.3 Games

As well as social AR apps, games have been one of the key content categories to have introduced AR to the mass market. The phenomenal success of Pokémon GO from Niantic really kick started a trend for AR gaming. It is a huge international hit, with over 147m monthly active users by May 2018, over a billion downloads by early 2019, and more than $6 billion in revenue by 2020.

What made it unique is the combination of the physical and digital worlds to create a location-based AR experience. Pokémon (pocket monsters) are scattered throughout the real world, and players must move around to collect them. When the player encounters a Pokémon, it is shown in AR mode as if it were present in the real world. They can also use the Pokémon in battle, again at specific real-world locations (Pokémon Gyms). The gameplay experience is further integrated with real world location – for example, water-based Pokémon are found near water in the real world.

As well as its success with gamers, Pokémon GO is an interesting case study from its success with advertisers. As the Pokémon are scattered throughout the real world, they have been used to drive footfall to real world locations. The first example of this was a partnership with McDonald's in Japan in 2016, where McDonald's locations became Pokémon Gyms. This attracted an average of an extra 2,000 customers per day to each location. US carrier Sprint later partnered with Niantic for a similar promotion for its 10,500 retail locations across the US. More recently, AT&T partnered with Niantic and its later Harry Potter: Wizards Unite AR game, turning AT&T's 10,000 retail locations into Inns and Fortresses to attract customers.

AR gaming doesn't have to involve traveling beyond the living room, and one innovative example of this is Mario Kart Home Circuit for the Nintendo Switch. Players race with actual physical toy karts, which are equipped with cameras. Tracks are set up in their own home, with augmented reality providing all of the graphical flair you would expect in a conventional Mario Kart game. The kart and the furniture are real, the other graphics are an AR overlay.

Figure 7: X-Boom AR Game (Source: Huawei)

Using the HMS Core AR Engine, Huawei has also developed many games with Chinese partners, such as Tencent, NetEase, Perfect World, and Miniwan Technology, creating innovative gaming experiences and developing the AR ecosystem in China. In X-Boom, AR animals appear overlaid on the real world, and the player must shoot them.

4.1.4 Education

AR has been used to create fun and innovative educational experiences. Unlike some of the other categories of apps, many of the educational applications come from existing book publishers, broadcasters and other companies and charities already involved in education – the existing industry has been enthusiastic about adopting AR. This has often happened with telecoms industry partners, and therefore this category of AR could be an important one for mobile carriers addressing the AR market.

A good example of this is the Big Bang AR app from CERN (Conseil Européen pour la Recherche Nucléaire, or the European Council for Nuclear Research) in conjunction with Google Arts & Culture. It uses AR to show the story of the formation of the universe from the big bang, using hand tracking to allow users to set off supernovas or hold planets in the palm of their hands. In this way it brings a new level of interactivity to learning.

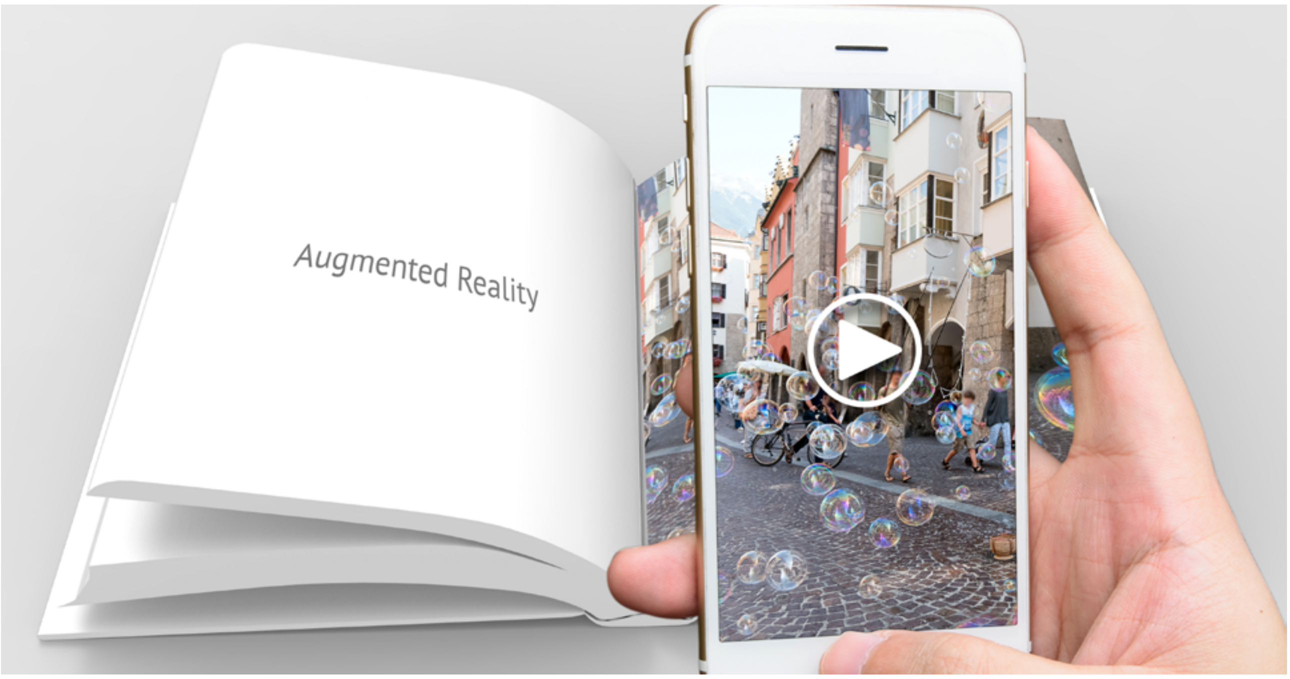

Figure 8: AR Book Concept (Source: Shutterstock)

Another example is the ELLE PLUS app powered by Huawei's HMS Core AR Engine. Hearst, a leading global media and information company, launched virtual models for its magazine SuperELLE through its flagship app ELLE PLUS. This combination of art and education with the latest technology has been steadily gaining traction. (see figure 9)

Figure 9: Elle's SuperElle app was developed with Huawei's AR Engine (Source: Huawei)

LG U+ has worked with 24 publishers, including DK, Penguin Random House, and Oxford Press to bring a range of educational AR books to users. A broad range of titles are included, with 10 new books added each month. As well as using AR to make story books more interactive and stimulating to young children, educational titles also include interactive AR games and puzzles to enhance the learning experience.

4.1.5 Retail

As seen in the previous use cases, AR social and games services are often integrating with retailers and brands. The ability to overlay virtual objects onto real world objects is a natural fit to “try before you buy”, and the ability to place virtual objects in real world locations can provide an added incentive to attract customers into stores or restaurants.

Dedicated retail apps exist as well. LG U+ subsidiary eyecandylab launched the augmen.tv service in 2019. By holding the phone up to the TV on partner home shopping channels, users can “pull” an item from the TV into their own room, move it around and interact with it, and position it in the room to see how it looks. They can also buy it directly by tapping on the object.

Figure 10: AR Furniture Placement Concept (Source: Shutterstock)

Retailers have also launched their own apps. The IKEA Place app allows users to place full size models of IKEA furniture in their own homes to see how it would look, and if it will fit, before buying. It offers genuine utility to the consumer. Other furniture companies have also launched similar apps, and AR capabilities are rapidly becoming commonplace.

JD.com, a popular online retail platform in China, has developed AR capabilities using the HMS AR Core Engine. For example, consumers can preview how furniture would look in their own homes. This improves user experience and has resulted in an over 19.2% increase in conversion rate for furniture and other goods.

Furniture is not the only type of home decoration which is leveraging AR to allow consumers to make buying choices. Wallpaper and paint companies are taking a similar approach, using AR capabilities to detect the walls and then overlay a new color or pattern. Some, such as the Graham & Brown Decorating app, add an extra level of utility. It uses the AR capabilities to also measure the walls, giving the consumer an estimate of how much paint or wallpaper they will need to buy.

Huawei considers AR to be geometry-based intelligence. In other words, it's a digital reflection of the physical world. Apple's LiDAR was initially used for modelling and measuring. Apple has launched its AR-based Measure app. Huawei and Google have also launched their own measuring apps using AR. These applications use AR-based measuring technology to get distance information by processing and analysing point clouds. Test results show Huawei's measuring technology is 30% more accurate than those of Apple and Google. Many scenario-based applications, such as modelling, home decoration, and lifestyle, can also use AR measurement.

4.1.6 Navigation & Tourism

Navigation is another key area where AR functions are being used today. Google has added AR functions to both Google Maps and Google Earth. As well as the obvious utility with more intuitive navigation, “pins” can be overlaid on real world locations such as restaurants or landmarks to give the user easy access to extra information.

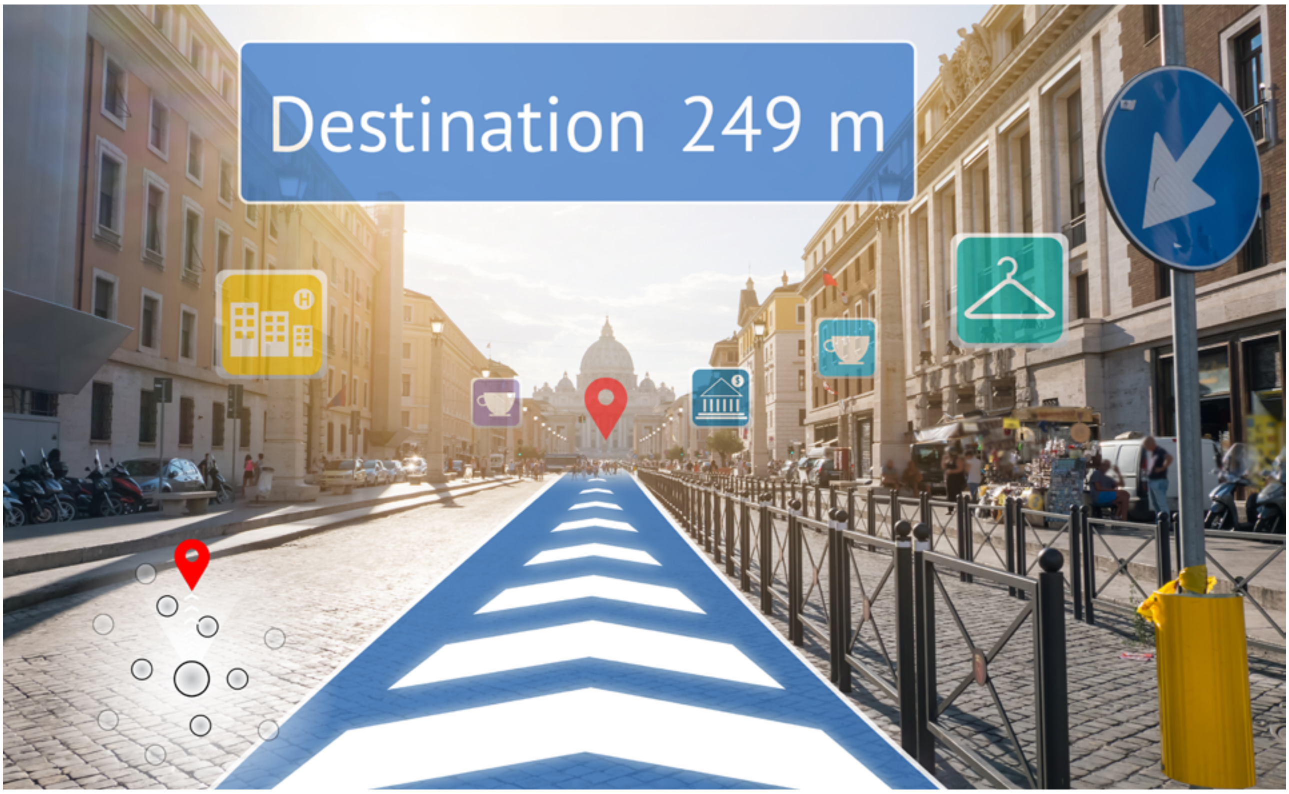

Figure 11: AR Navigation (Source: Shutterstock)

Mobile carriers have also been active in navigation and have a potential advantage over OTT players such as Google by leveraging 5G Positioning. One example is LG U+ and its Kakao Navi service (see figure 11). With more accurate positioning than GPS, it can provide lane-level guidance for drivers. 5G Positioning can also work indoors, giving a further advantage over GPS-based mapping. The additional external-facing sensors on AR devices can be used to alert drivers of potential hazards.

Baidu Maps offers lane-level navigation via differential corrections sent on the China Mobile network, initially in Guangzhou, Shenzhen, Suzhou, Chongqing and Hangzhou. Test results show that Huawei's HMS Core AR Engine has greatly improved the stability and accuracy of Baidu Maps.

Huawei's Cyberverse technology, powered by the AR Engine and high-precision maps, has been applied in HUAWEI Flagship Stores, as well as on the Bund in Shanghai, in the Dunhuang grottoes, and in cultural sites in Beijing. It supports AR navigation, cultural relic display, and fusion of the real world with history.

The functionality provided by these AR navigation tools can also be extended to provide an AR tourist experience. Moving beyond the smartphone, Telefónica worked with content partner Mediapro and local transport company TMB to integrate AR screens on tourist buses in Barcelona. The 5G network streams rich media geo-localised content to provide an interactive experience.

West Lake AR Tour is an innovative application for tourism. The West Lake in Hangzhou, China, a UNESCO World Heritage Site, is a popular destination for international and domestic tourists alike. Visitors can now enjoy an engaging and immersive experience through the "West Lake AR Tour" feature provided on the mobile app West Lake in the Palm. When visitors hold their phones up to a scenic spot, their phone screens will display background stories. The 1.4 km-long AR-enhanced scenic route includes Ping Hu Qiu Yue (Autumn Moon over the Calm Lake), Crane Release Pavilion, Tomb of Su Xiaoxiao, and Yue Fei Temple. The app also provides AR navigation, tour guides, and shopping guides.

An interesting use of AR for tourism is the Conhecer Almeida solution. A small town in Portugal, Almeida's castle was destroyed in the Napoleonic wars – making it a challenge to attract tourists. Through AR, the castle can be brought back, and as tourists stroll amongst the ruins, they can see and explore the castle as if it were present in the real world. As well as exploring the castle itself, a number of AR hotspots create a complete guided tour around the historic town.

In addition to smartphone usage, in-car AR HUDs are seeing rapid uptake in the automotive sector, enabled in part by the move towards connected cars. A good example of this today is the Mercedes S-Class AR HUD. It provides instrument data, navigation information, and includes a warning system for obstacles. Huawei has also launched AR-HUD products to provide drivers with advanced AR navigation and interactive experiences.

4.1.7 Health & Fitness

Phone usage of AR in health and fitness is somewhat limited given the form factor of the device; the user cannot have their hands free to perform activities. However, there are some interesting examples. Golfscape AR gives golfers accurate distances, overlaying relevant data on the real world. As it's used between shots, the experience works on a mobile phone.

However, it is really the early implementations of AR glasses that really show how the health and fitness market can be revolutionised by AR. Designed in conjunction with the US Olympic Cycling team, Kopin Solos AR cycling glasses provide considerable utility to the rider. Although they are relatively simple device – a monocular headset with a 5mm transparent HUD display, paired to the smartphone – even this form factor gives a lot of utility to the rider. Navigation, speed, distance, and heart rate are some of the key data that can be displayed. The integrated audio allows for voice control (very important in a hands free device), voice chat with other riders, and audio navigation directions.

4.2 Enterprise Use Cases

In contrast to the consumer space, headsets are the dominant device. The hands-free nature of dedicated headsets allows workers to perform tasks assisted by AR. As shown in the use cases below, these can range from the simple (picking items in a warehouse) to some of the most complex tasks possible (AR assisted surgery).

Google Glass is used by DHL to drive a more accurate, productive and efficient picking process in its warehouses. After a successful trial in 2015, AR glasses are now a standard part of its warehouse operations globally and improve productivity by an average of 15%.

Figure 12: AR assisted picking (Source: Shutterstock)

Another common use case in enterprise is remote assist. Thyssen Krupp uses the Microsoft HoloLens' AR capabilities to guide onsite service technicians through the repair process for its elevators, as shown in figure 23. They can also use the front-facing camera to do a video call to a remote specialist. This "see what I see" remote assist use case isn't using the AR capabilities of the device directly, but shows how the array of external cameras and sensors provide utility to the end user. Huawei's AR Remote Collaboration, which is based on the HMS Core AR Engine, is now serving many partners including a leading aircraft manufacturer, a popular luxury car brand, and a major iron and steel company in China (see figure 13).

Figure 13: Huawei AR Remote Collaboration (Source: Huawei)

Mobile operators have also been involved in enterprise deployments of AR, particularly when mobility is required. Providing AR for use in ambulances is one example of how the 5G network can be leveraged. Vodafone Italy's connected ambulance again uses the HoloLens device in similar ways to the example above. Ambulance staff can use the AR to be guided through procedures, and the "see what I see" functionality is also available that they can receive remote assistance from, and collaborate with, staff at the hospital.

Verizon has been working with a range of partners as part of its 5G First Responder Lab initiative. They include Qwake, which make specialist AR headsets for firefighters. It uses an Infrared camera to see through smoke and uses that data to create an augmented image to help firefighters navigate through the otherwise difficult to see environment.

The use of AR to improve surgery is one of the most advanced use cases. A team at Imperial College London has been using the HoloLens to take CT scans that have previously been completed and overlay 3D digital models of them onto a patient's limb during reconstructive surgery. The technique has been used to help surgeons successfully move blood vessels from one part of the body to another to help open wounds heal. Multiple surgeons wearing HoloLens headsets can also see what their colleagues are specifically looking at, allowing greater collaboration.

4.3 Predicting the Apps of the Future

As can be seen from the preceding sections, the enterprise applications space is already extremely well developed. It addresses a broad range of opportunities from relatively simple shelf-picking apps in logistics, to cutting edge novel surgery techniques. Headsets are already the primary form factor, which opens up additional utility through the hands-free nature of the device.

Although there are some extremely successful consumer apps, they are relatively few and far between, and only exist in a handful of app categories. The smartphone form factor is limiting – although emerging devices such as Kopin Solos are beginning to demonstrate the benefits of hands-free interaction.

What can the use cases today tell us about the likely successful apps of tomorrow, when consumer AR headsets become prevalent?

1) Social and Communication

- Communication will be more about shared experiences than casual chat
- One significant difference is that unlike the smartphone the camera is pointing away from, not toward, the user's face. This fundamentally changes the nature of communication
- The common enterprise use case of remote assistance is a similar "see what I see" communication mode. Rather than talking to a person, I am seeing where they are and what they are doing.
- In order to see the other user, it may be more natural to view them as a hologram positioned in the real world rather than in a small video window in the corner of my gaze. An early implementation of this is Microsoft's Mesh.
- Huawei launched its own digital avatars service last year to meet these market requirements in social and communication, allowing users to take "selfies" with animated avatars. Future enhancements will include greater levels of interactivity.
- Users will also be able to share virtual objects. In an enterprise setting, this may allow for greater collaboration, or for enhancing education. It will create new shared experiences beyond what is possible through conventional video chat.

Figure 14: AR Avatars (Source: Huawei)

2) Education

- AR education apps will become even more popular
- This will be driven by increased investment from governments and other bodies in technologies for remote education and the transition of learning materials to digital formats
- For example, the EU's Digital Education Action Plan aims to support digital transformation in member states at all levels of education
- A study as part of the action plan found that almost 60% of the respondents had not used distance and online learning before the crisis. Today, 95% consider that the COVID-19 crisis marks a point of no return for how technology is used in education and training

3) Navigation

- Navigation will underpin other applications
- Understanding where the user is and what they are doing to provide contextually relevant information will provide a seamless AR experience
- As the user moves around the real world, digital objects from multiple sources might persist. For example, creatures from a game might be shown even when the player is not actively playing, reviews a friend has left about a restaurant might appear as the user walks past its location, or interactive shopping experiences may show when the user is close to a retailer that they use regularly

- The Planet-Scale AR Alliance, which includes mobile carriers Deutsche Telekom, EE, Globe Telecom, Orange, SK Telecom, SoftBank Corp., TELUS and Verizon, as well as content provider Niantic, is working to make this a reality by leveraging 5G networks

4) Games

- We anticipate “co-located” gaming experiences
- Multiplayer will be simultaneous gaming in real world locations, with virtual objects and creatures synchronised so that multiple players can all interact with them simultaneously
- Niantic’s Lightship games development platform aims to help bring these types of games to market

5) Health and Fitness

- We expect this category to drive early sales of AR headsets
- While holographic communication and multiplayer AR games are technologies of the future, fitness apps can have value to users today, as demonstrated by the early Kopin Solos device (see 4.1.6)
- Health and fitness apps helped prove the value of smartwatches to consumers and provided a key target segment for marketing

05

Local versus Cloud Apps

As seen in the previous section, AR applications can be extremely varied. Some have rich graphics with precision placement onto the real world required – one of the most extreme examples being the HoloLens surgery. Others are relatively simple – the Solos smartglasses only display the HUD information with text and 2D graphics which persist in a window at the edge of the user's vision rather than being mapped to real-world objects.

Today, much of this is done on the device. Graphics or other data are downloaded onto the device in advance as part of an app, and the precision positioning is also typically done locally. However, as discussed in the devices section, we anticipate that in order to create lightweight and low-cost consumer AR headsets, much of the computing power will have to reside elsewhere. In future, we anticipate that much of this will be offloaded to the cloud. Even in the case of a smartphone-tethered AR headset it makes sense to shift to a cloud-based app model to ensure battery life is not adversely impacted (a common complaint about AR apps today). Rendering complex 3D scenes and the AI required for precision positioning are likely features which could be shifted to the cloud.

As discussed in section 4.3, navigation is a category of app which is likely to underpin other experiences – notably triggering new experiences as the user moves into a relevant location (such as entering a retail store). In this case, it may be more convenient to the user for AR events to start without the user having to download a specific app first. This is sometimes referred to as the "internet of space" concept. Rather than typing a URL into the browser, the user can access relevant data and services by visiting an actual location. A potential future standard which may underpin this future mode of interaction is WebXR, being developed by W3C, with notable contributors being Google and Mozilla. However, as is often the case in nascent markets, there are few standards in place yet for AR, and today it is fragmented. As well as device fragmentation, there are a range of different development platforms, offering different functions.

5.1 AR Development Platforms

5.1.1 On-device App Tools

Apple's ARKit and Google's ARCore, are tools for on-device app development, each addressing only their own OS. They can be used for facial recognition for chat filters, and have some limited capabilities for mapping a physical space, aimed at anchoring virtual objects in a physical space rather than navigation. It's worth noting that of the AR headsets available today, almost all run some version of the Android OS. The only major exceptions are the very high-end headsets; the HoloLens runs Windows and Magic Leap has its own OS, Lumin.

Huawei's AR Engine and its tools support its family of devices, and is more fully featured than ARKit or

ARCore, with additional functionalities such as hand and full body motion tracking. They also help explore innovations such as the world's first large-scale object modelling.

In order to support the content development of AR Engine, Huawei launched HUAWEI Reality Studio, a multi-platform 3D editor, which provides 3D scene editing, animation production, event interaction, and more to help developers quickly create 3D interactive scenes. HUAWEI Reality Studio can be widely applied for AR content development in industries such as education and training, e-commerce, and entertainment. An advantage of Reality Studio is that it can be used to develop 3D interactive scenes without any knowledge of 3D technology. HUAWEI Reality Studio is compatible with HUAWEI MatePad and can display 3D scenes directly with facial, gesture and planar AR functions..

Developers wanting to address multiple platforms might use 3rd party developer tools which integrate with multiple devices, and the most popular of these is Unity. Facebook and Snap both also have developer tools (Spark AR and Lens Studio respectively) which are hardware agnostic, but these are aimed at creating content within their specific apps rather than providing general tools for developer use. They are mainly aimed at marketing and retail use cases. The key features are facial and body recognition, for chat filters and for virtually trying on clothes or makeup.

5.1.2 Enterprise Tools: Device and Cloud Combined

The major enterprise toolkit for developers is PTC's Vuforia. It features more advanced environment scanning than the more consumer-centric toolkits, and is also able to track objects in the real world. This adds additional utility for verticals such as logistics or manufacturing. It does support relatively low specification devices perform these functions by offloading some capabilities (such as image recognition) to the cloud.

Microsoft's Mixed Reality platform and Wikitude are the main competitors to Vuforia. Wikitude has competitive functionality to Vuforia, again with a cloud element to its offering. Both Wikitude and Vuforia support a broad range of headsets.

Although Microsoft has the largest market share (by revenue) for AR headsets, its Mixed Reality tools actually support not only its own hardware but a broad range of other devices as well. Like Vuforia, it offers the capability to offload some functionality to the cloud through Microsoft's Azure. Microsoft's cloud offering also offers cloud rendering of 3D objects, allowing more capabilities to be offloaded to the cloud than its competitors.

One other feature of Microsoft's offering that is unique is the holographic communication elements. Originally called Holographic, this was relaunched in early 2021 as Microsoft Mesh. Again, it supports multiple devices, including both AR and VR headsets.

5.1.3 Cloud AR Development Tools

There are also a number of cloud-centric developer tools. AWS offers Sumerian, which like the Azure offering includes cloud-based rendering. It is aimed at creating browser-based AR applications.

One of the more specialised tools is Niantic's Lightship. The developers of Pokémon GO have leveraged their world maps and aim to create "planet scale" AR location-based experiences, giving multiple users the ability to interact with virtual objects simultaneously. Although aimed at the games market, the utility of this goes beyond gaming, as noted in the previous section.

06

Network Enablers for AR Use Cases

5G and Edge Computing play a prominent role in the evolution of AR. While older networking technologies can give an adequate experience, they lack some of the valuable capabilities that make for a better and more reliable experience.

Network connectivity is essential to connect AR devices to remote computing resources, typically in the cloud

Why are networks so important for AR? In part, to integrate the AR experience with other machines, such as other AR users, IoT devices and databases. Equally important, the network is essential to connect AR devices to remote computing resources, typically in the cloud. While in principle it is possible for an AR device to be self-contained, in practice, concerns about cost, weight, volume, heat and battery life force designers to relocate a portion of computation elsewhere. Like the Nreal Light, we anticipate smartphone tethered devices to form the bulk of the consumer AR shipments. Smartphones, too, are battery powered devices with limited computing capabilities. Cloud computing – see section 6.6 below - is a more practical solution – and using the cloud requires network connectivity between device and cloud data center.

From a network perspective, AR is a real-time or near-real-time application. AR traffic is generally asymmetrical. In the downstream direction, from the network to the device (User Equipment -- UE), it consists of compressed video, 3D models, still images and text. Video traffic is bursty, with relatively high utilization during scene changes and low utilization at other times. Peak rates are typically 3-5 Mbps for SD video, 8-10 Mbps for HD and 25-35 Mbps for UHD/4K. Average rates vary however and can range from hundreds of Kbps to Mbps.

Upstream traffic - from UE to network -typically consists of compressed video in addition to spatial and viewer pose tracking. Upstream video bandwidth depends upon the number and resolution of cameras in the device. Some have as many as nine cameras, including independent cameras for eye tracking. More typically, a consumer AR device will have one HD- or UHD camera for “see-what-I-see” use cases and a low-resolution camera for motion tracking. Peak rates are typically 3-5 Mbps for SD video, 8-10 Mbps for HD and 25-35 Mbps for UHD/4K, and average rates can range from hundreds of Kbps to tens of Mbps. Spatial and viewer pose tracking contributes insignificant traffic.

6.1 3GPP AR Examples that can be delivered today... and some that come later.

Existing and foreseen use cases that work with Wi-Fi and 4G LTE are expected to work better and more reliably with 5G. Specifically, 5G can provide low and deterministic latency and high-precision location and positioning to improve the AR experience. In addition, Wi-Fi lacks the mobility and coverage of 5G and 4G LTE, and older Wi-Fi (Wi-Fi 5/IEEE 802.11ac etc.) suffers from uncontrolled latency.

Unlike other wireless networking technologies 5G offers low and deterministic latency, high-precision location and positioning, and mobility, all of which enhance the AR experience

To reach the largest possible market, AR applications need to be network agnostic. Different locations will have varying combination of Wi-Fi, 4G LTE or 5G and connectivity selection may be embedded in the device or via pairing, as described below. Of 63 AR device models on the market (primarily enterprise devices), 48 have embedded Wi-Fi connectivity, one has 4G LTE and one has 5G. We expect more 5G-enabled AR devices to be commercialized as 5G connectivity becomes more ubiquitous.

Five AR current device models, as well as additional anticipated announcements, will pair the devices with a smartphone. The phone then provides connectivity and an associated rate plan, without an additional mobile device subscription. The paired smartphone also offloads processing to reduce the weight, volume- and energy-requirements for AR headsets.

Samsung and Apple are expected to introduce their AR headsets as accessories for their 5G 'flagship' devices - likely including the next version of the Galaxy, and the iPhone 13, respectively. The Nreal Light tethers to selected Android smartphones. Operators presently sell it bundled with a 5G smartphone. Because of the coupling with 5G devices, consumer AR over 5G is expected to grow with diffusion of 5G to consumers.

As 5G becomes widely adopted, future use cases are likely to appear that depend on 5G capabilities including deterministic low latency, coverage, mobility, and precision positioning.

6.2 QoS Characteristics for AR over 5G.

3GPP TR-23.501 lists six Quality-of-Service (QoS) Characteristics associated with each QoS flow:

1.Resource type (Non-Guaranteed Bit Rate (GBR), GBR, Delay-critical GBR)

2.Priority Level

3.Packet Delay Budget including Core Network Packet Delay Budget

4.Packet Error Rate

5.Averaging window (for GBR and Delay-critical GBR resource type only)

6.Maximum Data Burst Volume (for Delay-critical GBR resource type only)

And also, a QoS Profile, consisting of as many as six of seven parameters:

1.5G QoS Identifier (5QI); and

2.Allocation and Retention Priority (ARP)

For each Non-GBR QoS Flow only, the QoS profile may also include the QoS parameter:

3.Reflective QoS Attribute (RQA).

For each GBR QoS Flow only, the QoS profile shall also include the QoS parameters:

4.Guaranteed Flow Bit Rate (GFBR) – Uplink (UL) and Downlink (DL) and

5.Maximum Flow Bit Rate (MFBR) - UL and DL; and

In the case of a GBR QoS Flow only, the QoS profile may also include one or more of the QoS parameters:

6.Notification control

7.Maximum Packet Loss Rate - UL and DL

Some AR apps, e.g. relatively simple AR games of today such as Pokémon GO or Let's Hunt Monsters, are satisfied with effectively 'Best Effort' service, such as standardized 5QI number 7 which specifies a Non-GBR QoS Flow, Priority 70-100 ms Packet Delay Budget i.e., Latency, and a 10^{-3} Packet Error Rate. Consumer AR applications of today would tend to fall into this category.

Other, primarily B2B applications today (but which may include consumer apps in the future such as co-located gaming), have more stringent requirements for latency and guaranteed low packet loss rate, as specified for GBR and Delay-critical GBR.

6.2.1 Resource Type

Guaranteed Bitrate (GBR) requires reservation of bandwidth and other resources throughout the mobile network. If there is no disincentive to use them, human behavior predicts that all QoS flows would do so regardless of need, thereby reducing the useful capacity of the mobile network. To avoid this, GBR and Delay-Sensitive GBR flows must be priced as special services not only to monetize the additional value delivered, but also to ensure that user applications reserve no more bandwidth than they need on a per session basis.

Non-GBR QoS flows follow the Internet's 'Best Effort' paradigm whereby each data flow receives a roughly fair share of total bandwidth, and the network delivers data if it can, when it can. Since the Internet's QoS mechanisms are rarely offered by public fixed networks, consumer AR devices must generally work over Best Effort/Non-GBR flows.

IP networks often lack explicit congestion notification. They signal that they are congested by increasing delay and ultimately dropping packets.

Adaptive Bitrate (ABR) video coding adjusts to deliver varying levels of video quality or 3D images that match the available bandwidth during periods of congestion. In the worst case, the video freezes or buffers, noticeably downgrading the user experience. Simple text, graphics and still images also try to adapt using the Internet's TCP or QUIC protocols. Upstream, spatial and pose tracking may be more tolerant to packet loss, at the expense of user experience. To avoid charging, pre-paid and other value-oriented consumers will choose non-GBR service, even if quality of experience is not the best.

For premium paid B2B use cases, as well as premium consumer experiences, the GBR resource types offer strong assurances of low packet loss rate. The Delay-Critical GBR resource type assures low latency, as discussed below. The Guaranteed and Maximum Flow Bitrates, Averaging Window and Maximum Data Burst Volume need to be matched to the performance characteristics of the coder.

6.2.2 Latency

Overall Latency, and specifically packet delay budget is often the most important QoS characteristic for AR in B2B and premium consumer applications. Virtual images must register spatially and temporally with the real world. Excessive latency degrades that registration. As a result, misregistration can break the desired illusion that the virtual images are part of the real world and distort the perception of spatial relationships between real and virtual images.

- Spatial misregistration is perceived by users as an uncomfortable viscous or 'swimming' motion, or as smearing and/or strobing ('judder').

- Temporal misregistration manifests itself as lag between an action e.g., a keypress on a game controller or a gesture, and its effect on the virtual image.

Latency has real human factors consequences

Both effects can cause discomfort to the user, ranging from vague irritation to nausea, as discordant motion upsets the human vestibular system. In applications like first person shooter gaming and training, human performance can be affected by less than 100 ms – in some cases as little as 15 ms -- of temporal latency.

In the broader sense, AR latency or interaction delay is measured across the entire system, from 'motion-to-photon'. The principal delay is due to intensive AI and graphical compute processing in the cloud, while only a minor portion or 'packet delay budget' is allocated attributable to the network as indicated in the Exhibit below.

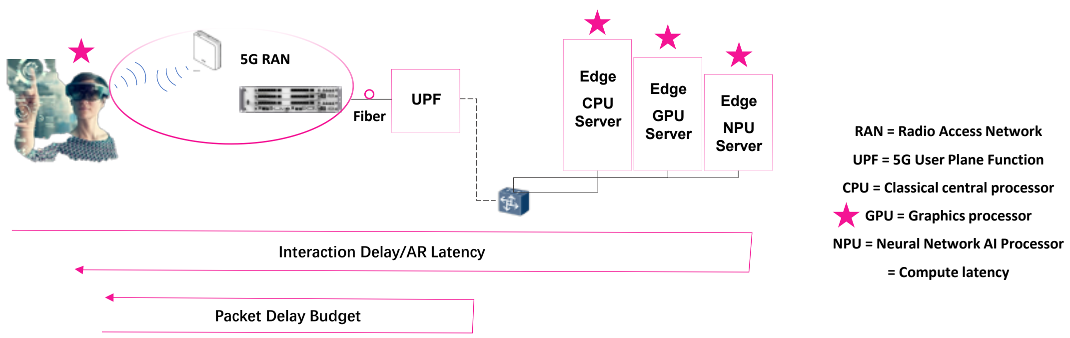

Figure 15: Interaction Delay vs. Packet Delay Budget (Source: Strategy Analytics Service Provider Group)

Unfortunately, interaction delay requirements vary for each application and it is difficult to quantify a single interaction delay requirement, much less a packet delay budget requirement. That depends on factors such as the nature of the application, complexity of the virtual image, speed of motion, resolution of the display, frame rate, and how processing is split between headset, tethered device, edge and cloud.

Techniques like 'motion prediction' and 'post-render warp' can mitigate latency-induced impairments, at some cost in local, edge or cloud processing. Consumer devices and applications tend to be more latency tolerant than B2B ones, and this tolerance is necessary in order to meet consumer price points. This means that the maximum packet delay budget for AR can vary over a wide range from 100 ms to 1 ms.

Operators may encounter Wi-Fi 6 (IEEE 802.11ax) as a competitive alternative to their 5G private network offerings. There is a difference. Wi-Fi 6 differs from earlier Wi-Fi solutions in that it offers several classes of service including low latency, using mechanisms similar to those in 5G. However, it is still a contention-based protocol. So-called 'hard' QoS guarantees are highly inefficient and 'soft' QoS is more of an objective than a guarantee. In addition, pre-Wi-Fi 6 devices – presently almost all of the installed base – do not participate in the IEEE 802.11ax priority scheme, and therefore may interfere with Wi-Fi 6 QoS. By contrast 5G latency guarantees are deterministic: the network will always deliver low latency packets on time. For more tolerant AR applications occasional late-arriving and dropped packets can be acceptable. For the most exacting ones however, e.g., surgical navigation, Wi-Fi 6 might be considered inadequate.

6.3 Accurate Positioning is Another Benefit of 5G

3GPP Release 16 introduced a new positioning architecture, methods, and reference signals for 5G for both indoors and outdoors. Combined and under the right circumstances these capabilities can offer accuracy to within a few centimeters. Reference signals in the 5G positioning architecture include internal sensors, Global Navigation Satellite Systems (GNSS, including GPS, GLONASS, Beidou, and Galileo) and Wi-Fi Positioning System (WPS), as well as 3GPP Radio Access Technology (RAT) signals, e.g., Uplink Time Difference of Arrival (U-TDOA) and RF pattern matching. Location accuracy is improved by combining data from multiple sources, since not all reference signals are always available – for example GNSS does not work indoors.

Huawei's Location Kit fuses GNSS, Wi-Fi and 4G/5G positioning information in a Development Kit (DK) for selected smartphones

For example, as mentioned above, Baidu Maps offers lane-level navigation via differential corrections to GNSS. China Mobile and Huawei recently demonstrated indoor positioning at a Metro station in Souzhou.

More accurate positioning opens up possibilities for new AR use cases, as described in Section 4. Examples include navigation, tourism, and kinetic multi-player games. Navigation can be enhanced through the addition of lane-level navigation that depends on sub-meter position accuracy.

In addition to more accurate positioning, 5G can also improve the AR experience, by reducing phone power consumption relative to the additional computational power required for alternative accurate positioning systems, such as visual positioning.

6.4 Outdoor mobility is necessary for many AR use cases.

Over the next few years 5G coverage is expected to become ubiquitous outdoors, particularly in urban settings, large indoor venues such as stadiums and public transportation hubs and as private networks in locations like factories and hospitals. Presently, homes, offices, cafes, and retail shops tend to rely on Wi-Fi or use both Wi-Fi and 4G or 5G. Standardization work is underway in 3GPP and the Broadband Forum to converge 5G services with residential broadband and in-home Wi-Fi, for example the Broadband Forum 5G Wireless Wireline Convergence (WWC) initiative. Some AR applications, such as the Ikea Place app, are more likely to be stationary and used in places equipped with Wi-Fi. For those that are primarily used "out and about", Wi-Fi connectivity alone is inadequate, because it lacks ubiquitous coverage and mobility.

Wi-Fi cannot support Vehicular and Pedestrian Mobility. Many AR applications either intrinsically require vehicular speed mobility or are likely to be used in a moving vehicle; for example, AR-assisted automobile navigation, tour bus enhanced information and AR games played in a car. Others require at least pedestrian speed mobility; for example, foot navigation and tourist guides. Wi-Fi does not offer seamless mobility even at pedestrian speeds, and cannot maintain connectivity at vehicular speeds.

Thus, to be truly general purpose, AR devices must have both Wi-Fi and 5G connectivity, either embedded or via a tethered or paired mobile device.

6.5 Edge Compute and Storage essential for ultra-low latency

One of the most important components of the packet delay budget in modern networks is called propagation delay - the speed that data travels through the atmosphere or fiber. The operative number is the speed of light though glass i.e., 4.9 microseconds (μs) per km. That means that 100 km of fiber equates to almost one millisecond (ms) of round-trip delay. While the speed-of-light through glass is a physical constant, propagation delay can be reduced significantly by reducing the length of fiber between a device and computing resources. In addition, switches and routers can add significant variable delays, especially when congested. A single hop may consume 10-20 milliseconds (ms) depending on traffic, line rates, and architecture. In a packet-optical metro network, there can be several router hops between a 5G Centralized Unit (CU) and the large regional data center location. Operators can eliminate router hops by using a 'flattened' Optical Transport Network (OTN) architecture and adopting wavelength switching to the extent possible.

As networks become ever faster, the product of distance and the speed of light and router hops dominate latency.

The best way for operators to reduce propagation and router hop delay is often to reduce the distance from processor resources and cut the number of router hops.

This establishes the requirement for computing and storage at the 'edge' of the network i.e., close to the end user geographically or in terms of propagation and hop-by-hop delay. This edge service architecture is referred to as Multi-Access Edge Compute (MEC). For network service providers, the edge can be located in structures like legacy central offices, mobile base station equipment huts or even outdoor ruggedized street cabinets. In private enterprise networks, MEC resources can be located on the customer's premises for security and very low latency.

The figure shows how applications can access processing via eNodeB or gNodeB at an Edge Computing /MEC Platform (MEP) – in the center. Applications can also leverage very fast access to both 5G Core Services (5GC) and remote Over the Top (OTT) high latency (typically >200ms) Cloud hosted Apps.

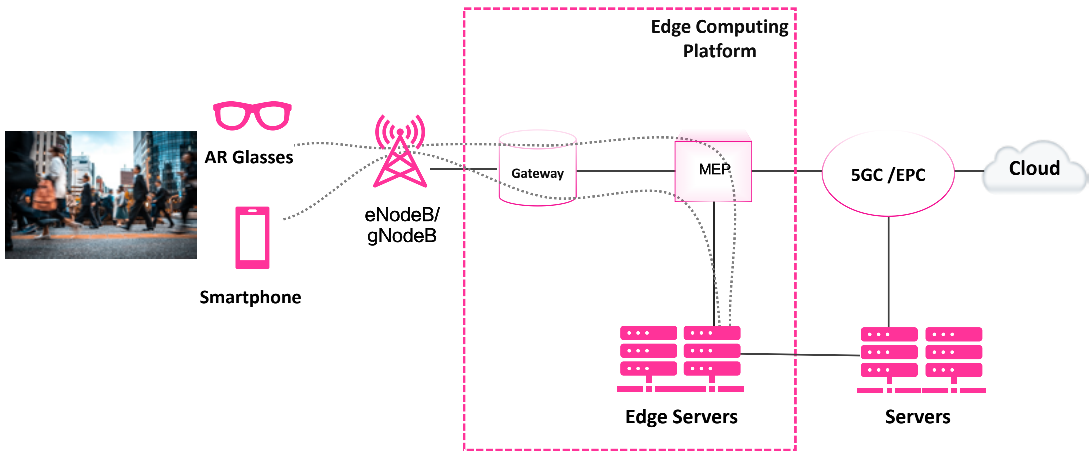

Figure 16: Significant parts of Augmented Computing can be done at the Edge (Source: Strategy Analytics Service Provider Group)

Cloud Native AR apps can be decomposed in a way that allows their component micro services to be dynamically instantiated in containers on either edge or remote servers. Policy parameters can then determine in real time where instantiation will occur to meet specific micro service QoS parameters.

Workloads can therefore be allocated for processing and storage across data centers or edge servers. Thus, the latency sensitive front end of an AR application can be hosted at the edge, while the less latency sensitive back end can be in a distant, lower cost hyperscale data center. Non-cloud native applications can also reside entirely on edge servers if appropriate storage and compute capacity have been deployed.

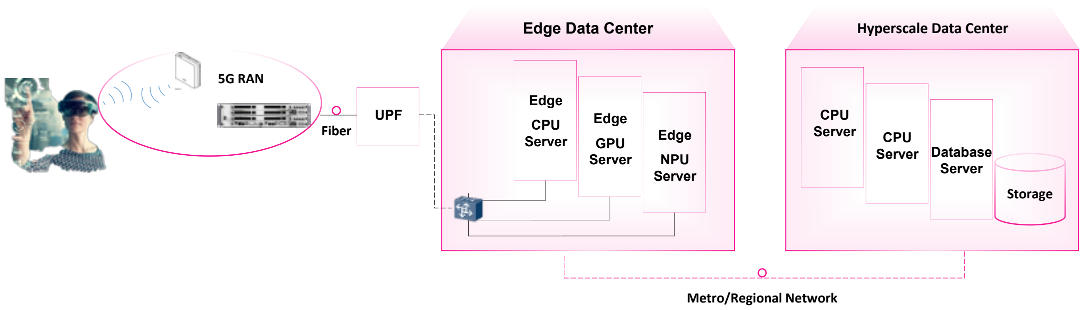

Figure 17: Workload Distribution of Cloud-native AR allows for Processing at Edge and Centralized Regional Data Centers (Source: Strategy Analytics Service Provider Group)

'Edge Cloud' data centers typically host graphics processing units (GPUs) and neural network processing units (NPUs), in addition to classical CPUs with FPGAs and accelerators These new processors are shared, programmable resources optimized for object rendering (including 3D), machine vision and AI. Meanwhile, the application's backend processing and databases may be separately located at a possibly distant hyperscale data center, where the benefits of cloud economics are more fully realized.

Communication Service Providers (CSPs)are uniquely advantaged in MEC, since network equipment space - such as legacy central offices and macro sites –which they already own - is ideal for edge cloud processing. Central offices are a particularly valuable strategic asset, as they are somewhat densely spaced, are located on the metro and access networks, have backup power, have cooling, and were designed to support large, heavy switching equipment. That uniquely positions CSPs to host MEC servers very close – typically a few km except in rural areas – to users and eNodeB/gNodeB sites. Some operators are considering placing MEC servers in outdoor cabinets, bringing edge computing even closer to the user. This is another competitive advantage that CSPs enjoy, since they have organization and expertise in siting, permitting, engineering and construction, which hyperscalers lack.

6.6 Cloud Core network and Hyperscaler Interoperability

Developer communities play an important role in cloud ecosystems. CSPs need to work with them to encourage innovation. That includes supporting as many cloud development environments (see 5.3 above) as possible, both cross-platform and cloud provider specific. Business models vary by country and target market and CSPs need to be responsive to that. This may include interoperating with one or more of the leading hyperscalers.

Multi-Access Edge Compute (MEC) must create a Network environment that facilitates Innovative OTT apps.

An early version of a Multi-Access Edge Compute Architecture that facilitated MEC Apps. was pioneered by ETSI in 2017 and is shown in the figure below. Several intense discussions ensued as to whether the OTT Apps and the Cloud Hyperscalers or the CSPs would provide authentication and load management functions and several versions have evolved. ETSI has now attempted to reconcile an approach with 3GPP that also incorporates Open RAN intelligence. See ETSI Press Release and Recommendations for MEC integration into 3GPP 5G systems October 2020. Going forward ETSI is still working on MEC to further define heterogeneous and inter-MEC systems coordination with cloud resources.

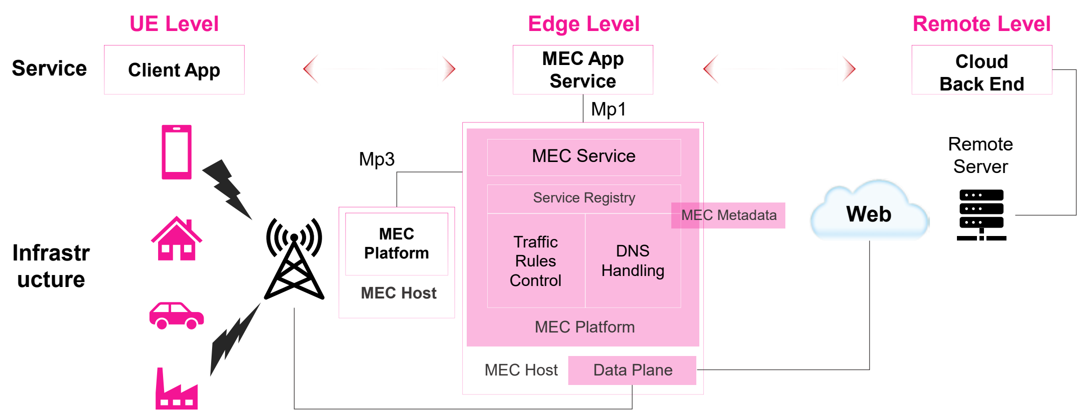

Figure 18: MEC Architecture for OTT 3rd. Party Developers that host on Cloud Hyperscalers (Source: Strategy Analytics)

As the figure above shows, the MEC Host is deployed at the network edge as part of a secure MEC platform (MEP) with the compute, storage and network resources that run applications/microservices in containers. The MEC platform also offers RESTful APIs that allow third-party applications. to discover, advertise, consume and offer MEC enabled services.

Although this model can turn CSPs into a ‘bit pipe’ unless they are careful to add additional value, it has been widely adopted by Cloud Hyperscalers and their OTT developer communities for many smartphone app deployments.

Despite the commoditization of CSP connectivity services that this OTT model implies, smart CSPs should still be able capture value from the Cloud Hosted AR apps, especially when as they increasingly host the associated high-performance micro services at the edge and offer significant value with intelligent managed QoS.

In addition, it is critically important that the CSP leverage Pooled Network Slicing – see section below - to offer guaranteed QoS with the necessary bandwidth and connectivity to deliver capabilities at a price point that no Hyperscaler can do alone. By putting multiple capabilities together as the figure below shows, 5G and Cloud Computing can come together to deliver the requirements for highly innovative AR apps.

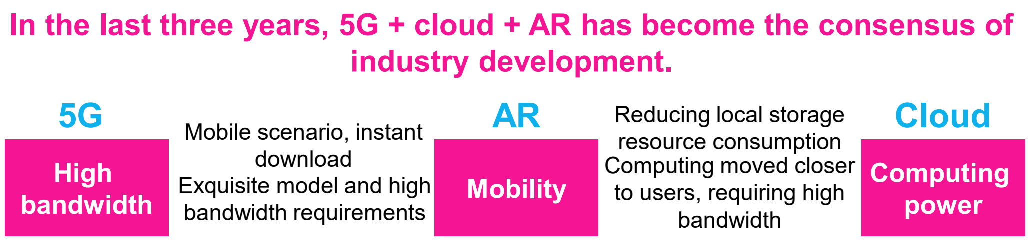

Figure 19: 5G and Cloud Computing will together meet AR Requirements (Source: Huawei)

6.7 Network Slicing – Cost Effective Guaranteed Consumer QoS

5G Network Slice Selection (NSSF) and Management (NSMF) allows each AR application /session or service flow to characterize, request and receive exactly the Type and Class or Quality of Service it needs including latency, security and privacy requirements.

5G Slice Management for AR should operate as part of broad Network Slicing solution for multiple classes of traffic handled as separate Network Slices but sharing a common physical resource pool. In later 3GPP releases that common pool of network resources should allow mobile operators to capture TCO savings of 20 – 30% with dynamic virtualization of multiple simultaneous Service Slice Types (SSTs). See Strategy Analytics Report 'Driving 5G Monetization with Network Slicing: Potential Business Models'.

Service providers can therefore use Network Slicing to support consumers' low latency QoS AR apps. without premium pricing by capturing savings from virtualized shared slicing. Operators can also leverage the economics of Network Slicing to offer superior value on a wholesale basis to OTT Hyperscalers who wish to deliver great user experiences via smartphones and glasses at both indoor and outdoor locations but who are unwilling to pay a premium price for guaranteed latency and bandwidth. Enterprise users with high value dedicated AR Network Slice based apps for Manufacturing, Heads up Displays etc. are, however, expected to pay a premium price for guaranteed AR QoS.

07

Recommendations

7.1 Devices

In the consumer AR space, the main challenge for devices is reaching an acceptable price point. The likelihood is that this will mean the smartphone will be leveraged to provide some of the sensors, processing power, and most notably WAN connectivity. Device vendors with smartphones in their device portfolio are likely to be at an advantage, as they will be able to have a tight integration between the devices. They will also already have distribution for smartphones and other wearable devices through carriers in place, so they can build on these existing partnerships.

Although mobile operators are unlikely to play a significant role in device manufacturing, they will play a key role in distribution. This also means that non-smartphone, independent AR vendors can address this market. Nreal is an example of an independent player achieving market traction. They have managed to do this by creating partnerships with mobile operators (LG U+, KDDI and Vodafone). Since the Nreal Light is smartphone tethered, using operators for distribution is a sensible market approach. Some carriers may also desire devices from non-smartphone vendors as part of their device portfolio mix, as this gives them more control over bundling.

Looking at this from a mobile operator perspective, planning for AR should begin as soon as possible. The mix of devices and the bundles they might wish to offer to consumers should form part of this planning. With smartphone OEMs likely to enter the market soon, carriers should consider how they will promote what is likely to be an OEM-defined bundle of hardware with their own data plans to consumers. For AR headsets from non-smartphone OEMs, such as Nreal, carriers should plan how these devices will be offered. For example, should they be sold separately from smartphone, or perhaps bundled in with devices from OEMs which do not manufacture a corresponding headset?

Since carriers will not control device specifications, it will be challenging to plan in advance for AR content, since the content accessible will depend on the functionality of the device. Developing early relationships with AR headset vendors and sharing technology roadmaps will help to overcome this challenge. Knowing what device specifications will be will enable carriers successfully offer data plans bundled with the right content for the device mix. Carriers with particular content strategies should seek out relevant AR devices which will showcase that content. The “Mapping Use Cases” chapter of this report can be a useful reference.

Some AR vendors (existing smartphone OEMs and independent vendors) may also choose to go to market directly. This may be challenging without a strong existing brand – but it may be a strategy followed by Facebook, which has announced that it is working on AR devices. This will have a number of implications for mobile carriers. If the data traffic of the headset is using the smartphone, this will make it challenging for mobile carriers to differentiate the traffic. Carriers also risk losing out on offering AR-specific data plans, or AR content bundles. Developing good distribution links with AR device vendors is therefore also important for carriers and having a strong device offering will help them maintain a competitive position.

In the enterprise AR market, the price point of devices is related to value derived. Unlike the consumer market, there is not a price point which must be reached before the device becomes appealing. This is demonstrated by the success of Microsoft's HoloLens, which as well as being the top enterprise AR device is also the most expensive. The standalone nature of the device is important for enterprises, opening up use cases and maintaining security. Many device vendors are selling directly to enterprises. However, there are a number of mobile operators with large enterprise client bases, and partnerships with operators can still be a valid route to market.

In the enterprise space, customers are typically looking for a solution to a business problem, not shopping for devices. A go-to-market strategy should be different for the enterprise space. It needs to include not just the devices but other elements such as software, development tools, and relevant connectivity solutions. Partnerships with other relevant companies will also help vendors with a successful market entry.

7.2 Networks

Of the challenges facing operators and vendors for future networks, several stand out a particularly important to AR.

Advanced AR devices can be a significant traffic source. Networks need to be engineered, deployed and provisioned with adequate capacity to serve the likely numbers of AR users with moderately high rate bursty data flows, e.g., up to 35 Mbps peaks and 15-18 Mbps averages. AR devices can also be significant sources of uplink, as well as downlink traffic. Planners should also consider pop-up clusters of AR devices and viral AR applications.

AR systems are, to varying degrees, sensitive to latency. For a few use cases, packet delay budgets can be as little as 1 ms in order to provide the best experience. Networks should be designed to minimize delays in the RAN and metro network, including both switching/routing and propagation delays. Flattened topologies using OTN should be considered as an alternative to packet-optical architectures to minimize delay due to router hops. Low latency slicing and differentiated QoS should be implemented throughout the network.

Edge computing is a valuable way to reduce latency. Edge servers and data centers should therefore be located as close as economically possible to the receiving device or users. Central offices and large macro sites are a valuable strategic asset in this respect. To maximize the served market size, Service Provider MEC needs to interoperate seamlessly with hyperscaler app servers at the cloud edge.

Precision location is important to some AR applications. GNSS augmentation should be provided as a service for outdoor use. Indoors location is a greater challenge, since RAT signals, internal sensors and Wi-Fi positioning are likely the only sources of location. Technology development is still required to achieve centimeter-level accuracy.

Uplink bandwidth is critical for a good quality AR experience. As AI is increasingly applied to device-cloud collaboration, AR devices will have the ability to capture and send back multi-channel videos or images larger than 500MB. Backhaul latency is key to providing a premium end-to-end service experience. In the network design stage, uplink spectrum resources should be allocated based on specific application scenarios and scope to deliver a premium end-to-end AR experience.

7.3 Business & Ecosystem

AR is not only about the device, the content, or the network. It is about combining the capabilities of all 3 together to create a compelling offering. This means that a successful market approach will include all these elements and include strategies for dealing with the challenges of each of them. Therefore, a partnership approach, bringing together expertise across all of the different areas, will be a likely feature of the most successful market entrants. Steps that companies can take today include:

- Find and select the correct partners from across the value chain for a successful entry into the AR market
    - Device vendors, both smartphone OEMs launching AR headsets, and independent vendors
    - Tools for consumer and enterprise AR application development
    - Consumer apps developers to create innovative 5G and MEC enabled applications
    - Specialist app developers for bespoke enterprise solutions
    - Mobile operators, particularly those with a 5G network offering
    - Hyperscale cloud service providers: partnership, edge cloud services provider, reseller
- Consider their competitive positioning in AR relative to others in their market. For device vendors and carriers, AR can be a differentiator
- Understand which market segments will be most interested in AR
    - Consider how to bundle devices, data plans and content, in partnership to appeal to those segments

- AR application aggregators (such as the XR telco content alliance) can provide carriers with a consistent flow of quality AR applications and give app developers an additional distribution channel. AR application aggregators can also provide business functions such as application management, certification and flexible tariff policy management. Telcos can use AR aggregators to manage third-party and their own AR applications.

- Carriers could leverage a location-based RCS (rich communication services) message channel to establish a link between cloud AR applications and consumers.

A number of examples of these partnerships are already developing. They include:

- LG U+ has developed a range of content for smartphones, much of it in collaboration with content partners. It has also invested in building volumetric video capture studios to enable its content partners to create compelling content. It is working with Nreal to bundle headsets with flagship 5G smartphones. These are discussed in full in the white paper LG U+ 5G Strategy Update.

- It has also taken a lead setting up a collaborative content creation venture, Global XR Content Telecom Alliance, with KDDI, China Telecom, Bell Canada, Qualcomm and content studios.

- Niantic, the developer of Pokémon GO, is leading up the Planet-Scale AR Alliance. Other partners include Verizon, SoftBank, EE, Orange, SKT, Deutsche Telekom, Globe, TELUS and Telstra

- In addition to that partnership, Verizon has partnered a number of diverse companies in the AR space, including specialist AR headset vendor Qwake, content partner Snap Inc, surgical AR application developer Medivis and the Metropolitan Museum of Art.

- AWS' Wavelength service enables ultra-low latency applications to be deployed on infrastructure located in partner operators' edge data centers. Partners include KDDI in Japan, SK Telecom in South Korea and Verizon in the US.

- Huawei has been building a large global developer community around its AR Engine and development toolkit. The Engine has been installed more than 900 million times, and over 1,400 apps have been created by third party developers from Huawei's developer community. Huawei remains open and actively participates in various standards organizations, contributing technologies, white papers, capability sets, scenarios, equipment specifications and standard specifications.

These partnerships are creating the connections across the value chain for a successful AR market entry.

7.3.1 Mapping the Landscape

In order to create the right partnerships, players in the AR market need to consider the entire landscape across use cases, devices, network and cloud capabilities. The table below maps examples of key future consumer-centric use cases (section 4.1) to device, network and cloud requirements, and the second table maps the enterprise use cases from section 4.2.

		Device	Network	Cloud
Social and Communication	Simple	Camera 2D display Facial recognition sensors to position filters	~ 1Mbps downlink < 100 ms latency	Cloud for P2P communication only
Social and Communication	Holographic	Camera 3D display External facing sensors to position avatars or other shared objects in real world	Up to 100 Mbps downstream for volumetric video streaming <100 ms latency	Edge computing for real-time 3D graphics and AI processing. Non-real-time processing in scale-up data center.
Navigation		2D display GPS+5G positioning External sensors	~1-2 Mbps bidirectonal <100 ms latency but less gives better experience Location accuracy within ~50-100 cm for roadway lane keeping	Mix of local and cloud data for static objects (buildings, streets) Cloud data for real time tracking and additional map "layers" (such as traffic density)
Games	Simple	2D display GPS+5G positioning External sensors	~1 Mbps downlink ~300 kbps uplink <100 ms latency but less gives better experience May need 10 cm location accuracy in the future	Graphics most often stored locally Positional and other data requires cloud
Games	Planet scale persistent multi-user	3D display External facing sensors to position avatars or other shared objects in real world, detect gestures, etc.	70 Mbps peak downlink for complex UHD scenes ~20 ms latency May need 10 cm location accuracy	Edge computing including real-time graphics, location and AI processing. Non-real-time processing and storage in scale-up data center
Health & Fitness		GPS Ability to attach to additional sensors e.g., on a bike or other wearables to measure heart rate	<1 Mbps each direction <100 ms latency 50-100 cm location accuracy, ~1-5% speed accuracy	Data fusion in cloud not in real time

Figure 20 Mapping Consumer Use Cases

	Device	Network	Cloud
Bin picking	External sensors 2D display	~ 1Mbps downlink < 100 ms latency	Integrate with inventory system
Remote AR Assist	Camera 2D display External facing sensors to position avatars or other shared objects in real world	>4-5 Mbps peak uplink for HD video and external sensors ~1-2 Mbps downlink <50 ms latency	Integrate remote assistant video and audio with exploded parts diagrams, service manuals, etc.
Connected Ambulance	Camera 2D display External facing sensors to position avatars or other shared objects in real world	>4-5 Mbps peak uplink for HD video and external sensors ~1-2 Mbps downlink <50 ms latency	Integrate video with manipulation of simple avatars and text
Firefighter AR Navigation	Infrared camera 2D display 5G indoor positioning External sensors	~4-5 Mbps downlink ~4-5 Mbps uplink <50 ms latency ~ 10 cm location accuracy	Fuse IR video with machine vision, AI –enhanced video, avatars, text, floorplans
Surgical AR Navigation	Camera 3D display External facing sensors to position 3D models and detect gestures.	Up to ~70 Mbps peak downlink for complex 3D images. 4-5 Mbps uplink. ~5-10 ms latency.	Edge computing including real-time graphics and AI processing. Integration with medical image database.

Figure 21 Mapping B2B Use Cases

08

Conclusions

AR has a truly transformative potential. It is already starting to deliver on this in the enterprise space. While the few hit consumer AR apps on the smartphone give a hint of the future, the advent of consumer AR headsets and their deep integration with 5G are likely to bring new use cases. In-vision augmentation of the real world will open up new possibilities.

The likelihood is that to achieve a mass market price point, consumer AR headsets will also be tethered to the smartphone. This is a natural pairing, since AR's main benefits come from mobility use cases. For a low-cost device, more processing will also have to be in the cloud. This means that the device, network and content will all have to work together in tandem to deliver the best possible experience. Partnerships across the value chain will be critical to allow the AR market to flourish to its full potential.

8.1 Huawei's Vision

Huawei's vision is to bring digital to every person, home and organization for a fully connected, intelligent world.

With the mass market adoption of future-oriented AR devices, a truly transformational era will arrive. AR can bring digital to every person, home and organization, to deliver Huawei's vision for connectivity. The hands-free nature of AR headsets will open up new use cases for consumers. These are far beyond what is available today through using smartphone-based AR.

Huawei is committed to delivering leading AR products and solutions that provide the strongest performance and the best experience. With our AR technology, products and expertise in geometric intelligence, we aim to build a human-oriented digital base for life, work, and production scenarios, supported by our digital technologies that enable high accuracy, high performance, and low latency. AR solutions form a key part of the company's all-scenario business strategy and its vision of an intelligent and digital world. Looking forward, Huawei is ready to work closely with partners and customers across the value chain to create a vigorous AR industry.

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