Augmented and Virtual Reality: the First Wave of 5G Killer Apps

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A TRANSFORMATIVE SHIFT SUPPORTED BY THE INTRODUCTION OF 5G

The synergistic relationship between upcoming technologies in the connectivity and computing space often leads to a revolution across markets. With applications and use cases morphing to take full advantage of new technologies, such as 5G, cloud, and edge computing, the industry is investigating new business opportunities, otherwise not possible before the introduction of these technologies.

This white paper will focus on augmented reality (AR) and virtual reality (VR), among the most attractive use cases for 5G. These technologies are promising to transform the way content is consumed and communicated, and will no doubt help a wide variety of industries increase productivity and change the way they do business. Workflow assistance and "see-what-I-see" remote interaction and guidance have seen strong uptake already among existing AR rollouts. ABI Research estimates the total AR market will reach US$114 billion by 2021, and the total VR market will reach US$65 billion within the same timeframe.

AR and VR have similar underlying technologies, but distinct experiences. As described in this study, both AR and VR applications can be very sensitive to network performance, as any associated hiccup can penalize the overall user experience. Today's typical 4G networks place serious limitations on AR and VR applications, such as latency and capacity, which can negate some use cases entirely. Although current 4G networks are sufficient for some early adopter AR and VR experiences, the introduction of 5G, which represents a considerable leap over 4G, will no doubt strengthen existing experiences, enable novel ones, and make them available for mass adoption. Offering much more capacity, lower latency, and a more uniform experience, 5G will not only improve, but will also be a requirement for some of the most exciting AR and VR use cases outlined in this paper: automotive content streaming, social sharing from event venues, next-generation video, and tactile Internet.

These key use cases impose diverse network requirements that go well beyond what 4G can deliver. For example, high-mobility automotive content streaming requires strong network uniformity, combined with increased capacity to handle growing bitrate requirements for content consumption. In the case of live streaming a sporting event on social media, the network is required to provide a very dense coverage and high capacity to bring AR and VR applications close to the end user and make the overall experience consistent throughout the venue. Next-generation video formats, like interactive 6 degrees of freedom (6DoF) video, will be most demanding in terms of bandwidth, with up to 10X the bitrate required for 4K video. Network requirements for remotely controlled devices and tactile Internet, on the other hand, are expanding. Introducing AR or VR into remote control intensifies latency requirements. Tactile Internet adds haptic feedback to remote control, creating an even greater need for ultra-low latency.

AR AND VR ARE PROMISING, BUT STILL REQUIRE DEVELOPMENT

AR and VR are unique in that the technologies have the potential to touch so many different markets, use cases, and applications, allowing the opening up of a substantial addressable market. However, both technologies are currently in their infancy and face several challenges.

On the hardware side, there is much progress to be made for both AR and VR, most of which will also have an impact on network performance requirements. Battery life for untethered devices is currently inadequate, as is processing for graphically intensive applications. Pixel density on current generation displays is lacking as well, most noticeably in media and entertainment scenarios in VR. Field of view is another concern, limiting usability in AR and immersion in VR. Standalone VR devices, housing all required components in a single device, will begin to grow over the next 5 years to compete with mobile VR. This introduces a difficult and novel hardware form factor to contend with, in addition to the individual component difficulties mentioned above.

Outside of AR and VR head-mounted device (HMD) hardware, supporting infrastructure is the next step. Building out 5G infrastructure will take time, but early identification of the most promising applications that rely on or can be improved with this infrastructure creates a stronger foundation for future growth. Enterprise applications for AR and VR are growing in attractiveness as ROI metrics, such as error reduction and employee efficiency, are identified and proven. As the hardware footprint continues to grow, the need for reliable and efficient connectivity will as well.

This white paper looks in detail at the network requirements of AR and VR use cases mentioned above. It will highlight the key challenges facing the current generation of networks in addressing these requirements and how 5G will help these use cases achieve their full potential for sustaining credible and lucrative business opportunities. Before looking at these use cases, let us first elaborate on the general benefits 5G brings to AR and VR applications.

THREE KEY ADVANTAGES OF 5G

5G networks are heterogeneous by default, offering different types of connectivity optimized for different types of services. They will offer enhanced mobile broadband connections, but will also support low latency and high reliability mission-critical services, which are necessary requirements for immersive AR and VR experiences. If one takes into account IMT-2020 guidelines, 5G promises to achieve goals, such as:

- 20 Gbps peak data rate
- 100 Mbps data rates, even at cell edges
- 1 million devices per km^2
- 10 $Mbps/m^2$ for area capacity
- 1 ms roundtrip over-the-air latency

Compared to 4G, this translates to targets such as a 10X improvement in throughout, a 10X decrease in latency, a 100X improvement in traffic capacity, and a 100X improvement in network efficiency.[1] As history has shown, an entire range of opportunities opens up when wireless connectivity becomes faster and costs less. Omnipresent connectivity spanning millions of bandwidth-hungry devices will push capacity requirements of the network even further, especially considering the visually-intensive data used for immersive AR and VR.

In addition, as 5G technology matures, it will become fundamental for AR and VR services and experiences to be ubiquitous across heterogeneous networks, including 4G, 5G, and Wi-Fi. Ubiquitous 4G coverage with Gigabit Class speed, which is expected to see commercial deployments starting in 2017, will be the foundation for initial AR and VR experiences, while 5G will be able to leverage more spectral bands and wider bandwidths to boost capacity.

In short, the usefulness of AR and VR going forward is heavily dependent on three primary network components: high capacity, low latency, and a uniform experience. Some applications rely on one component more than another, but supporting all three simultaneously is critical to enabling all AR and VR use cases under the same network.

CAPACITY

5G is expected to bring enhanced mobile broadband speeds to mobile networks and increase network capacity many times compared to previous generations. Capacity need is a result of two primary drivers: bandwidth per application and simultaneous usage of those applications. Although there are numerous compelling AR and VR applications, video is the most important and unique in its high bandwidth requirements. ABI Research expects a progression in demand from the current tens of Mbps per user to hundreds of Mbps per user in the 5G timeframe for premium content, delivered through AR and VR.

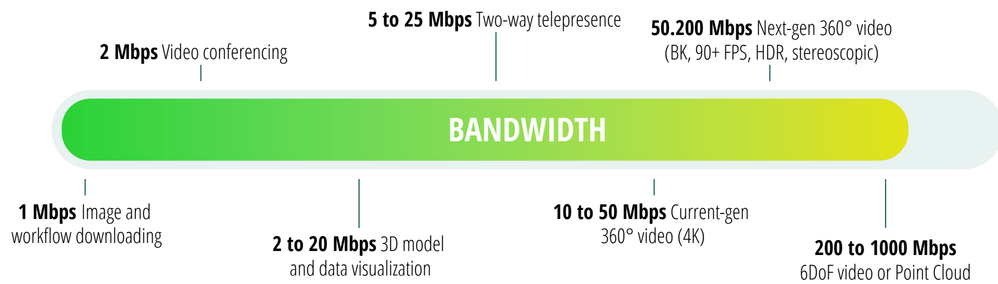
AR and VR Video will Drive 5G Capacity Improvements

The next generation of video includes new formats, such as stereoscopic, high dynamic range (HDR), and 360°, at increased resolutions (8K+) and higher framerates (90+ fps). Although basic implementations of these formats may be delivered through 4G networks, large-scale adoption of applications that use these formats will soon congest the network, thus rendering the user experience intolerable.

These new video formats will offer higher quality experiences, but at the cost of higher bandwidth. For example, higher resolutions are required for 360° video to maintain pixel density across the image, counteracting the close proximity, increased field-of-view, and optic losses associated with HMD viewing. Those higher resolutions bring higher bitrates. Stereoscopic video, which separates left and right eye views to create depth perception, thereby doubling the video streams, is required for immersive VR and AR viewing and further drives increased video data bandwidth. In addition, HDR video, which offers visual quality improvements in color fidelity and brightness, will become more mainstream and may increase bitrate by up to 20% depending on the HDR scheme and video format used.2 In terms of video compression, it is expected that H.265/HEVC will be the primary encoding and decoding format in the 5G timeframe, offering 30% to 50% improvement in bitrate reduction for similar quality as compared to H.264. Despite this efficiency, ABI Research expects AR and VR applications to push network requirements, with visual improvements and associated bitrate requirements outpacing compression improvements for several years.

The ability to view 360° video at 4K 30 fps, which requires 10 Mbps to 50 Mbps depending on quality selected when using the HEVC video codec, will soon be common and will likely be handled by existing 4G infrastructure. However, in the 5G timeframe, stereoscopic HDR 360° video at 8K 90 fps, which requires higher than 200 Mbps, will be feasible. Looking even further out, 6DoF video that allows translational movement (discussed in more detail in Section 3.3) presents novel compression and transcoding obstacles and requires 200 Mbps to 1 Gbps per user, which could challenge the cell capacity of current 4G networks.

Figure 1:The bandwidth requirements for streaming various visual content, especially video, will stress network capacity.



(Source: ABI Research)

Multiple users simultaneously consuming or sharing premium content is the other half of the capacity story. Current 4G networks will struggle when the number of concurrent users increases. AR and VR will compound this issue by adding many more concurrent users. For example, the vision for AR is the mass adoption of an all-day wearable device that is constantly connected, uploading and downloading vast amounts of data throughout the day. Image and video data will increase naturally with the visual nature of AR, and constant network calls for metrics such as location, status, and AI assistance will drive total requests and concurrency up even further. As AR and VR seep into the consumer space, these numbers will be exacerbated. For reference, ABI Research forecasts that the AR smart glasses installed base will reach 48 million units in 2021, with the VR device installed base numbering over 200 million units globally.

Breaking the Speed Barrier with 5G NR

5G networks are built to support very high bandwidth applications, while the standardization community is creating specific use cases around AR and VR and the video formats discussed above. The 3GPP is working toward a new radio standard called 5G New Radio (NR) that will use new technologies to increase network speeds to tens of Gbps. One of these technologies is millimeter wave (mmWave) communications, in which the frequency of the link is loosely defined as being above 24 GHz. This promises vast amounts of bandwidth (including unlicensed bandwidth) and capacity improvements. For example, several field trials have taken place during 2016 that broke the 10 Gbps barrier, often using more than 1 GHz or even 2 GHz of channel bandwidth.

There are several ongoing industry trials illustrating user-tracking pencil beams connecting the base station and the UE, allowing speeds of several Gbps. The added benefit is that these links are spatially separated, thus allowing mmWave spectrum to be reused even in the same cell for each individual user. However, there are several challenges to overcome before mmWave communications are used on a large-scale basis; for example, tracking hundreds of users in real time or dealing with non-line of sight connections between the base station and user device.

Nevertheless, mmWave shows great promise, and highlights one technology candidate for 5G NR that is not a simple evolution of existing 4G technologies. Lab trials are now advancing to field trials, and will soon create the mmWave radio technologies capable of supporting commercial networks. The speeds required by certain AR and VR applications will reach the Gbps limit of 4G networks, meaning that mmWave may be a key enabling technology for these applications. In addition to these higher bands, initial 5G NR deployments in licensed spectrum are also targeting lower spectrum bands, such as new spectrum around 3 GHz and 4 GHz.

LATENCY

Latency plays an important role for AR and VR experiences, but it is important to understand when low latency is crucial and what type of latency is being discussed.

Latency is Critical for Interactive AR and VR User Experiences

For non-interactive content that can use a buffer, such as a streamed 360° video, network latency is generally not an issue if the buffer remains, making this content more tolerant to higher and inconsistent latency. Interactive content, on the other hand, is more susceptible to network latency. Low latency is required to ensure responsiveness for certain user interactions, such as virtually shooting an opponent in online multi-player gaming, playing virtual ping pong, controlling remote machinery, or interactively collaborating on a vehicle design. In these scenarios, the visuals require a full rendering of the scene based on the additional interactions. If the network is transporting the interaction information, then a reduction in latency is paramount to the experience (e.g., it may be the determining factor between shooting your opponent or being shot by your opponent).

Head movement while wearing an HMD with head tracking is another specific interaction with distinct latency requirements that warrants more discussion. Motion-to-photon (MTP) latency is the time between an action (a head movement) and reaction (the display is updated based on the movement). When a user moves their head, the brain expects an instantaneous visual and aural update, so delaying that even minutely can be problematic. A MTP latency below 20 ms is currently targeted for many VR user experiences, but studies have shown that achieving a MTP latency of less than 15 ms makes the delay imperceptible to nearly all users. Considering the strict MTP requirements associated with HMD usage, ABI Research expects that AR and VR applications will keep MTP processing on the device (the HMD itself). There are hybrid-computing scenarios where 3D rendering happens off the device. PCs and game consoles tethered to VR HMDs are available today, while network edge or cloud rendering may be possible in the future. For these hybrid scenarios, ABI research expects that the processing will be intelligently split between cloud-based 3D rendering, which requires low network latency, and additional processing on the untethered mobile device to ensure high-quality visuals at a fixed low MTP latency.

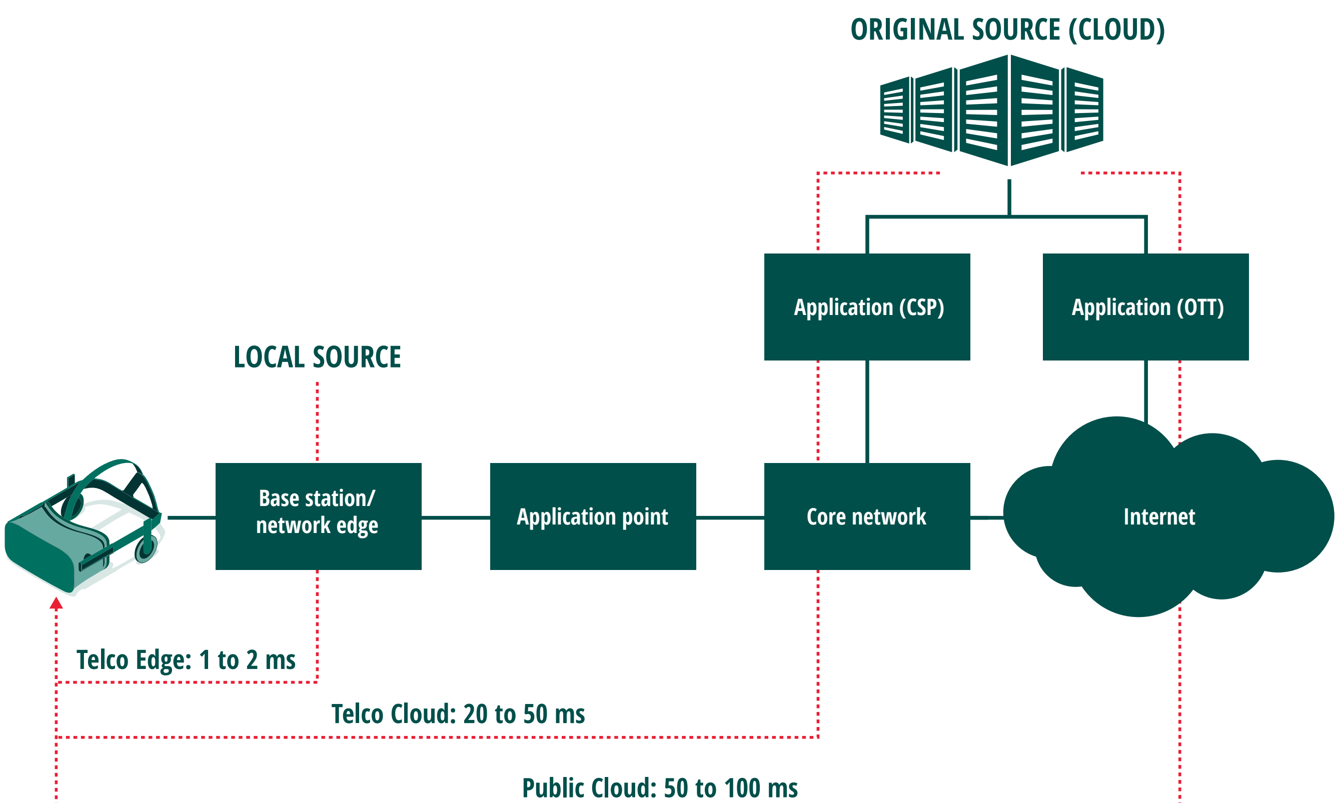
5G Latency Improvements

A major requirement of the 5G standard is ultra-low latency, with a targeted 1 ms roundtrip latency over the air. While 4G has already improved latency over 3G by flattening the network architecture, 3GPP is now also working to reduce over-the-air latency closer to the 1 ms range, guaranteeing an even lower latency.

Strict latency requirements that go beyond the air-interface latency are not specifically defined in standards because they should include additional network transport components that are scenario and deployment dependent. For example, a latency-sensitive application may require proprietary components today that are tightly integrated to deliver this functionality specifically, e.g., real-time banking transactions. This may translate to specific functionality at the base station, specific core network components, and proprietary software at the network control and business system domain. On the other hand, 5G promises to offer this functionality through a standardized and consistent manner.

Moving content and network functionality to the edge of the network can reduce latency, which will be required for applications heavily dependent on ultra-low latency. Applications that are required to span end-to-end, such as remote machinery control, will require 5G at least when dealing with long distances between nodes.

Figure 2: Network topology will significantly impact content delivery latency and thus user experience. The diagram shows three different network topologies and their associated latencies.



(Source: ABI Research)

5G latency can be broken down into three network topologies, assuming a roundtrip ping scenario:

- Public cloud to device: 50 ms to 100 ms
- Telco cloud to device: 20 ms to 50 ms
- Telco edge to device: 1 ms to 2 ms

These latency figures were derived from background research, including 5G-PPP targets[3,] ETSI, and ITU documents[4], and real-life 3G and 4G network latencies5. As 5G network architectures are yet undecided, it is not clear what end-to-end latencies will be achieved. The 1 ms over-the-air latency target for certain 5G use cases is very aggressive, but ABI Research has assumed latencies of this order may be achievable if an application is hosted at the edge of the network, e.g., in a Mobile-Edge Computing (MEC) server. For public cloud and telco cloud to device scenarios, core network improvements can be expected as 5G is built out, and the latency numbers quoted above will most likely become significantly lower.

The needs of each use case will dictate the network topology. For instance, a stadium can house content on-premises at the network edge, allowing for near-immediate upstream and downstream. On the other hand, mobile video streaming may need to stretch to the telco cloud or public cloud to access content.

UNIFORM EXPERIENCE

Enabling ultra-fast connections is relatively straight-forward; making sure that users get a consistent experience with ultra-fast connectivity is not. Reliably delivering bandwidth to a significant portion of mobile users is equally important and cannot be understated for AR and VR use cases. For example, delivering 10 Gbps to a stationary user with strong coverage is one thing, but maintaining an acceptable signal as the user reaches network edges, while minimizing low data rate areas, is paramount for AR and VR applications where stutter, lag, and general disruption is unacceptable for user experience and comfort.

High mobility use cases further emphasize this. For example, buffering video is much more disruptive while using an HMD with head tracking than on a traditional display. Also, highly variable network speeds can disrupt experiences in other ways. In highly immersive VR applications, picture quality fluctuations from adaptive bitrate can be distracting. Inconsistent roundtrip latency for input can also emerge from poor network uniformity, disrupting user experience and potentially barring input-critical applications from use.

5G is attempting to solve this challenge through two different methods: by becoming the "network of networks" that consolidates all previous networks into one and by introducing further advancements in network capabilities that also improve uniformity, including:

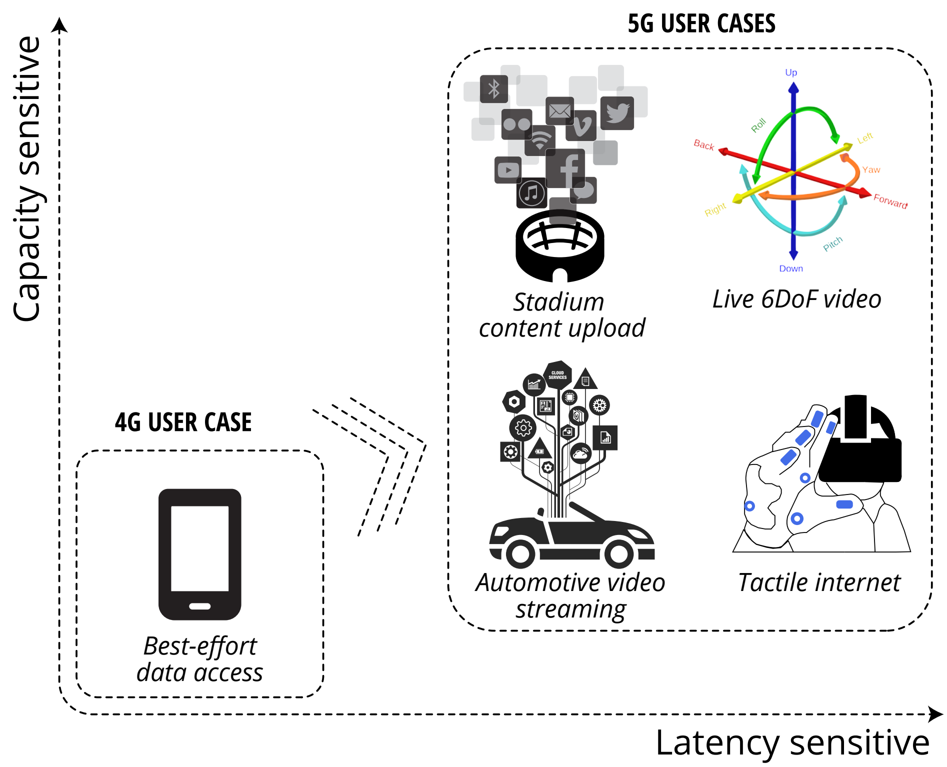
- The use of a large number of antennas (referred to as Massive MIMO) to steer the signal energy to the user's location increases both uniformity and overall capacity. IMT-2020 requirements call for >100 Mbps user throughput, even at cell edges, and not just multi-Gbps peak user data rates.
- Simultaneous multi-connectivity, in which a user is simultaneously connected to multiple 5G access points and across 4G and Wi-Fi deployments, will also increase uniformity. One key example is when a user may be simultaneously connected to a 5G mmWave and a 4G access point, providing a seamless mobility experience and the ability to send data on both links.

EARLY AR AND VR USE CASES AND 5G NETWORK REQUIREMENTS

AR and VR offer an immense number of promising applications. In enterprise verticals, AR and VR offer promising ROI, improved safety, and novel workforce capabilities, while in the consumer space, users are promised immersive content and new social experiences. Delivering these use cases from source to end user will tax existing networks and require the advantages of 5G to properly function.

This paper explores four uses cases: high mobility using automotive, high-capacity venue upload, high-bandwidth 6DoF experiences, and low-latency remote control, and to certain extent, tactile Internet, to exemplify the requirements that VR and AR impose on 5G in terms of capacity, uniformity, and latency.

Figure 3: The four AR and VR use cases described in this paper require 5G. The diagram shows the approximate connectivity requirements in terms of latency (x-axis) and capacity (y-axis) for each use case. Uniform experience, although not shown, is also required for each use case.



(Source: ABI Research)

HIGH MOBILITY EXAMPLE: AUTOMOTIVE VIDEO STREAMING

Current roadmaps suggest a working, but expanding 5G network map starting around 2020. Within that timeframe, the automotive landscape will also start to transition to semi-autonomous and fully autonomous vehicles, unlocking additional time for entertainment and productivity. Passengers in a traditionally piloted car or a "driver" and passengers in a fully autonomous vehicle will consume compelling AR and VR content while commuting. This use case is especially challenging for two reasons: high capacity and high mobility of users. The massive bandwidth associated with premium AR and VR content causes capacity requirements to scale up quickly, while users rapidly transition between cells.

As an example, traffic during rush hour on a highway can be dense. Assume that:

- Each car is 3 meters long and leaves a 9-meter gap between the car in front while driving 16 km/h. The highway has 8 lanes to be served.
- One cell tower is located directly at the highway with a cell radius of 500 meters, thus covering a stretch of 1 km serving ~667 cars.
- There is some level of autonomous driving in this timeframe. Assume that there are 1.0 potential AR/VR users (passengers of non-autonomous vehicles, or "drivers" and passengers of autonomous vehicles) per car due to increased carpooling, and that the penetration rate of AR or VR usage is 1%. Thus, we would have 0.01 VR or AR users per car.

If each VR or AR app consumes 100 Mbps, then this use case would consume 667 Mbps (667 cars x 0.01 users per car x 100 Mbps). For 10 bps/Hz spectral efficiency, the cell site would require 67 MHz of spectrum to support this capacity need. As autonomous cars reach the mass market, the percentage of people using AR or VR in the car increases, and thus the capacity required will increase significantly. Continuing the example with 10% penetration rate, we would need 10X more capacity, which can be solved through cell densification (decreasing the cell radius to less than 500 meters in this example) and more spectrum (which is only available at higher bands, including mmWave).

With mobility, network handoff can be troublesome for streaming content, but 5G adds the concept of simultaneous multi-connectivity to remove the need for a traditional handoff. Simultaneous multi-connectivity is especially helpful in this case since the user can simultaneously receive data from two cell sites in range, which also helps to create a more uniform experience. In addition, the potential for 200 Mbps bitrate streams highlights the necessity for 5G's promise of a more uniform and higher capacity network.

High Mobility Automotive Video Streaming	
Required Pillars of 5G	Capacity • Mobility • Uniformity
Technical challenge: Ubiquitous mobile multi-Gbps connections	Multiples of 100 MHz of spectrum per cell

HIGH CAPACITY EXAMPLE: SOCIAL SHARING FROM EVENT VENUES

Much attention is paid to downstream bandwidth with 5G. However, the upload side of the story is equally interesting and important, especially with the simultaneous usage of applications that would take place in a crowded event venue like a stadium. Not only will stadium goers be able to reliably and quickly upload their content, but those outside the venue will have a large selection of content to view. Social media services like Facebook Live, Periscope, Instagram, and Snapchat are made possible with highly connected and highly capable capture devices, such as AR glasses, smartphones, or other 360° cameras. The potential for tens of thousands of users to simultaneously upload content could bog down a network, and this is exacerbated in the 5G timeline with content increasing in complexity and size (e.g., pictures migrating to 360° videos). Imagine being at the Super Bowl and trying to live stream the kickoff, along with 50,000 other fans, using the multiple cameras in your convenient and hands-free AR glasses. That could easily be a 1.25 Tbps spike in bandwidth (4K 360° video @ 25 Mbps x 50,000 users) within the area of the stadium (0.1 km^2), reaching a total capacity of 12.5 Tbps/km^2 (=12.5 Mbps/m^2). Fans at home using VR will be able to enjoy these experiences in real time and feel like they are at the game as long as the network is not bogged down. For reference, IMT-2020 targets traffic capacity of 10 Mbps/m^2, which this scenario approaches or could exceed.

A stadium network implementation has the advantage of a more accessible edge network infrastructure, allowing for content created both on-site and externally to be housed on the edge for very low latency delivery. In a sporting venue, low latency is equally as important for downstream and upstream applications. Supporting high upload concurrency of rich data, with low delay, allows for near real-time content updates. On-site value-add stadium experiences, such as games, interactive video, crowd participation, etc., can be enabled with near real-time upload as well. This is especially pertinent as compelling home sports content consumption grows, and ticket sales are endangered. With many fans questioning whether tickets are worthwhile when their home viewing experience can be equal or better in some situations, these unique experiences can drive interest back to the stadium.

Stadium Content Upload	
Required Pillars of 5G	Capacity • Uniformity • Latency
Technical challenge: Total capacity per area	12.5 Mbps/m^2

HIGH BANDWIDTH EXAMPLE: 6DOF CONTENT

Next-generation VR and AR experiences will have 6DoF for the next level of immersion, allowing users to move within and intuitively interact with the environment. 6DoF content is an order of magnitude richer in naturalness and interactivity than 3 degrees of freedom (3DoF) video. Current 3DoF experiences, such as 360° video, allow the user to rotationally look around from a fixed position. 6DoF experiences, which are available in video games today, allow the user to move spatially through the environment just by walking or leaning the head forward. 6DoF head motion tracking is required to enjoy 6DoF content in an intuitive manner. One solution to provide precise 6DoF head motion tracking is visual-inertial odometry (VIO), which estimates the relative position and orientation of a moving device in an unknown environment using a camera and motion sensors. A huge advantage of VIO is that it can be processed on the HMD with no additional setup for a truly mobile experience, unlike other solutions that require external sensors, markers, cameras, or lasers to be set up throughout the room.

Synthetic (computer-generated) 6DoF environments can be rendered in the cloud today, while 6DoF video, sometimes referred to as "point cloud video," is in its early stages. Sports, tourism, education, and other forms of immersive video will flourish as 6DoF technologies evolve, but the current state is nascent. Most components of the video delivery pipeline are currently ill-suited for 6DoF video, including capture devices, production software, codecs, compression algorithms, the network, and players. 6DoF video also demands bit-rates in the range of 200 Mbps to 1 Gbps depending on the end-to-end latency. Overall, the pipeline must mature to enable the 6DoF content.

For these reasons, streaming live 6DoF content to deliver a "be there" experience is certainly a compelling and forward-looking use case, but also one that will require 5G and beyond. While streamed 3DoF video (360° video) content traditionally can cope with network latency via a jitter buffer, the rendering of 6DoF content is dependent on the user's head and body movements; hence, it is sensitive to bi-directional end-to-end latency as well. This use case is akin to streaming a video game, so end-to-end latencies must be on the order of a few tens of milliseconds. Network operators should be aware that a trade-off between latency and bandwidth exists for 6DoF content delivery. With lower end-to-end latency for communicating the user's movement, fewer viewpoints around the user need to be sent. For example, when end-to-end latency is on the order of 1 ms to 5 ms, then the bit-rate for 6DoF content can be reduced to ~100 Mbps to 200 Mbps. However, if the end-to-end latency of the system is 5 ms to 20 ms, then the bit-rate is closer to ~400 Mbps to 600 Mbps, because more viewpoints around the user need to be sent. As a result of this, 6DoF content will most likely be limited to edge streaming scenarios during the 5G timeframe.

6DoF Experiences	
Required Pillars of 5G	Capacity • Latency • Uniformity
Technical challenges: User throughput (bit-rate) & Latency	200 Mbps to 1,000 Mbps < 20 ms, the lower latency the better

LOW LATENCY EXAMPLE: REMOTE CONTROL AND TACTILE INTERNET

Remote collaboration through telepresence is a huge boon for enterprise use cases powered by AR and VR. Truly interactive remote experiences require low end-to-end latency often ranging from 40 ms to 300 ms, depending on the use case.[6] In general, reduced latency increases the amount of interactivity possible, thus expanding potential use cases to things like remote medical procedures, collaborative remote manipulation of objects, and online gaming. Remote machinery control through user-guided tele-operation, such as a remote control forklift, has a roundtrip latency threshold of ~100 ms. Consider that a single roundtrip communication between two mobile endpoints may involve four wireless link traversals (that equals two over-the-air roundtrips and two networks' transport legs). When accounting for processing latency within the endpoints, multiple edge network traversals, core network latency, and physical distance latency, it becomes clear that low-latency 5G edge networks are essential to achieving remote interactivity for AR and VR. As an example, enabling sub-40 ms end-to-end latency may require as little as 5 ms roundtrip latency for each of the two links if we allow for a 30 ms delay to the network.

Looking beyond the remote machine control of today to the tactile Internet of the future, research suggests that ultra-low latency feedback below 5 ms will enable novel uses of multi-sensory remote tactile control with responses rapid enough to be imperceptible to the operator.[7] Use cases, such as vehicle control, with fast motion involving the user, environment, or an object, require these ultra-low latencies, as latency is more perceptible in these cases.

Near-field remote control is most feasible early on and is a promising application of 5G with AR and VR. As 5G continues to evolve and be built out, long-range tactile Internet applications come into focus and become more attainable with 5G's aggressive latency promises.

Remote Machinery Control	
Required Pillars of 5G	Latency • Uniformity
Technical Challenge: Latency	< 5 ms latency for tactile Internet

CONCLUSION

5G is envisioned to bring higher capacity, a uniform experience, and lower overall latency—all of which are critical for AR and VR applications over a network—while also reducing the cost per bit. This white paper outlined four examples of AR and VR requiring 5G to empower new user experiences and improve existing ones as the number of users increases.

Semi-autonomous and fully autonomous vehicles present additional time for content consumption, but also challenging mobility and capacity requirements for network streaming. Applications at densely populated stadiums are already stressing wireless networks, and content upload by thousands of simultaneous users at a stadium will demand capacity on the order of 10 Mbps/m^2. The impressive growth of video will only become more substantial as AR and VR grow in market share, with next-generation content formats like 6DoF video stressing networks even more with individual data consumption in the range of 200 Mbps to 1 Gbps. Ideal end-to-end latency requirements in the 10 ms range for remote machinery control and tactile Internet will also push the boundaries of these networks, and could require over-the-air latencies as low as 1 ms. In a way, the AR and VR industry is thirsty for the capabilities 5G promises and this is a profound change in the way cellular networks have traditionally been developed: if you build it (the network), they will come (applications and users).

The uses cases outlined above illustrate that current 4G networks and their evolution will not be able to sustain a consistent user experience for many AR and VR applications, without which the industry will not be able to build solid business cases for these applications. Moreover, new use cases for AR and VR will manifest as the capabilities of 5G networks actualize. ABI Research expects AR and VR to transform industries, and 5G will be crucial in making that a reality.

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