White Paper: Here is Our First Real Glimpse at eXtended Reality (XR)

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1 Executive Summary

There has been increased interest in eXtended Reality (XR) which can create new human machine interfaces coming increasingly closer to replicating natural human movements, interactions, and experiences. The XR use cases include but not limited to virtual humans, training, 360 video, synthetic multi-user environments, holographic/volumetric video. XR includes technology-mediated experiences that combine virtual and real-world environments and realities, and X(R) is a catchall term for several different but related technologies including V(R), A(R), or M(R), though it also represents an undefined or variable quality/quantity. Most definitions of XR encompass platforms and content in which the user can take digital objects into reality, or, conversely, see physical objects as present in a digital scene. A couple of examples are immersing gamers in the action by putting smartphone display or headset screen right in front of eyes or adding game characters to real world surroundings. Despite the enormous potential afforded by XR technology, massive utilization of this tool still faces certain obstacles. Today XR connectivity is achieved via tethering to the PC and a Wi-Fi connection. Heavy compute requirements for XR services have seen a variety of players working to make XR experiences which are not bogged down by large device form factor or the need to tether. Despite the recent advances, the XR ecosystem needs to reduce the potential for cybersickness, heat generation issues as well as the limited processing power, storage, and battery life of small form factor of XR devices.

The industry hopes to make XR devices more portable and scalable operating on high bandwidth, ultra-low latency 5G connections, enabling to deliver immersive technology in many fields such as sports training, fan experiences, manufacturing, and gaming, etc through offloading parts of the XR processing to the mobile network edge.

Network operators play an important role in delivering the essential capabilities required by untethered XR experiences such as edge computing, high data transfer, low latency all of which will be delivered through the deployment of 5G.

In this White Paper, we provide an overview of XR landscape, use cases, challenges, high level device requirements, and network requirements for XR services. We also examine in detail the set of capabilities and roadmap based on XR product evolution and provide recommendations on the aspects necessary for onboarding XR devices and operation on the AT&T 5G network. Finally, we provide an outlook of future enhancements we expect in standards for XR.

2 Industry and Competitor Landscape

2.1 Competitors' Landscape

Operators are very motivated for XR immersive devices to drive 5G adoption.

T-Mobile

T-Mobile jumped in on the AR action starting in November 2019

T-Mobile announced that it was the exclusive 5G launch partner in North America for the Qualcomm Snapdragon Spaces XR developer platform.

T-Mobile plans to work directly with startups and developers through their XR Accelerator Program to build immersive 5G experiences for AR glasses, with industries like gaming and entertainment in its sights.

https://www.t-mobile.com/business/resources/articles/benefits-of-5G-for-innovation?cmpid=TFB_AF_U_21FRBSMKT_JYDY3XDG45GC6XES64192

Verizon

Verizon has been working with a range of partners as part of its 5G First Responder Lab Initiative. They include QWake, which makes 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.

Verizon has partnerships with Niantic which is leading up the Planet-Scale AR Alliance.

Verizon has also partnered with a number of diverse companies in the AR space including content partner Snap Inc., surgical AR application developer Medivis and the Metropolitan Museum of Art.

Verizon announced during 2022 Investor Day that they will partner with Meta (Facebook) to determine network requirements to support XR cloud rendering and low latency streaming, and measure impact for edge computing on key performance metrics for metaverse optimized performance.

2.2 Industry Landscape

Following are examples of industry developments:

- Facebook Oculus Quest 2 VR HMD has been very successful
- Facebook Ray-Ban Stories Glasses launched last Fall
- Samsung Concept Video on immersive AR glasses
- Sony PlayStation VR2 Headset announced in Feb 2022 and expected soon
- China market heating up with ByteDance Acquisition of Pico and Tencent Aquisition of Blackshark
- MediaTek RedCap modem in development will support R17 and Sub-6 1CC needed for lightweight AR applications
- Nvidia CloudXR (Server/Client/SDK) Enterprise Solution
- Google Cardboard HUD glasses
- Google Glass HUD glasses
- PC Connected AR HMD devices include HTC Vive, Microsoft HoloLens, and Meta 2 for gaming applications

Heads Up Display (HUD) devices are out of scope in this White Paper as they are not true XR devices

3 XR Devices and Form Factors

To experience the high-end virtual experience, the user needs a hands-free, mobile, and easily accessible device.

The head worn device is one of the key components to experience the AR/VR world.

High-end examples include Microsoft HoloLens or Oculus Rift head-mounted devices (HMD).

The Microsoft HoloLens is a wearable device with holographic see-through displays, 3D environment mapping as well as eye and hand tracking all powered by specialized processing unit and paired XR software to create interactive virtual elements interfacing with the hardware. Motion tracking and haptics as well as audio-visual output from the XR devices create the immersive, social, and meaning interactions between human and machines.

XR encompasses AR, VR, MR, and the areas interpolated between them. AR and VR devices share data rate, latency, and reliability requirements.

Following are the key definitions of the three XR device & experience types discussed in this White Paper.

Heads Up Display (HUD) glasses are out of scope in this White Paper as they are not true XR devices.

3.1 Augmented Reality (AR) Glasses and Experience

Augmented reality is the overlaying of digitally created content on top of the real world. Augmented reality – or 'AR' – allows the user to interact with both the real world and digital elements or augmentations. AR can be offered to users via headsets like Microsoft’s HoloLens, or through the video camera of a smartphone.

In both practical and experimental implementations, augmented reality can also replace or diminish the user's perception of reality. This altered perception could include simulation of an ocular condition for medical training purposes, or gradual obstruction of reality to introduce a game world. It is worth noting that there is a point when augmented reality and virtual reality will merge or overlap.

AR Glasses capture the live video of device's surroundings and adds visual elements, one basic example such as Amazon App can superimpose the virtual furniture in your room with your phone's display. However, AR is less stringent on the haptic component as users do not need to be immersed in its artificial environment

3.2 Virtual Reality Head Mounted Display (VR HMD) and Experience

VR is an immersive computing experience where the user's entire field of vision is filled via the device's play. You can play a VR video game with the phone in a VR headset to fully immerse yourself in the gameplay.

As virtual reality has evolved and found different uses in different sectors, several different definitions have emerged, most of which significantly overlap with one another. Discrepancies exist. The following elements, however, are near universal in framing what VR offers:

- Computer-generated stereo visuals which surround the user, entirely replacing the real-world environment around them. Many believe this definition rightly excludes 360 videos from true VR.
- Content is consumed and experienced from a viewer-centric perspective.
- Real-time user interaction within the virtual environment is possible, whether through detailed interactions, or simply being able to look around within the experience. Here the real-time element means response comes within a particular time interval that is specific to the application or field.

3.3 Extended Reality Head Mounted Display (XR HMD) and Experience

Technology-mediated experiences that combine virtual and real-world environments and realities. Here the "X" can be seen as a placeholder for V(R), A(R), or M(R), though it also represents an undefined or variable quality/quantity. XR covers the hardware, software, methods, and experience that make virtual reality, mixed reality, augmented reality, cinematic reality and others a reality. Most definitions of XR encompass platforms and content where the user can take digital objects into reality, or, conversely, see physical objects as present in a digital scene.

XR experiences include those where users generate new forms of reality by bringing digital objects into the physical world and those that see the bringing physical world objects into the digital world. One example is enabling VR real-world players to be superimposed into video games to bring real-world personalities to game streaming platforms.

XR experiences are made possible through combinations of XR applications/software and specialized hardware including but not limited to glass or head mounted displays, sensors, and motion controllers.

XR is used as an umbrella term and is frequently used as a casual shorthand to group technologies such as VR, AR, and MR together.

4 Challenges

4.1 Device Design Challenges

Despite the enormous potential promised by XR services, there are still certain obstacles in current PC based and standalone XR devices/services to make XR widely adopted.

Therefore, the overall market adoption of XR technologies is still slower than expected.

Following are the XR device design challenges which currently limit the wider adoption of XR devices:

1. Limitations in operational use and freedom of movement when tethered to a PC or a Wi-Fi connection
2. High computing demands for the rendering of interactive content at higher resolutions
3. Daytime visibility limitations – AR Glasses are not well suited for mobility due to the safety risks of view obstructing content
4. Stationary use – XR devices are best suited for stationary use cases given the safety and regulatory issues
5. On Device Latency
6. Battery life limitations when connected wirelessly or with continuous usage will have higher consumption rates
7. Device form factor is bulky and uncomfortable – no “wow” factor
8. Device Cost barriers
9. RF exposure close to the head
10. Size matters – modem and batteries need to fit in small and lightweight wearable AR Glasses and HMD

11. Need to scale with a “global SKU”
12. No integrated 5G solution will scale to a “global SKU” for a few years

4.2 Regulatory Challenges

Head worn device as one of the body worn devices falls under the portable wireless product category classified by FCC. When the device is used, it is in very close proximity to the human body. FCC has set a SAR (Specific Absorption Rate) limit of 1.6 W/kg. When a wireless device is used within 20cm of a human body, the body will absorb RF energy. SAR is a unit of measurement for the quantity of RF energy absorbed by the human body when a wireless device is used. SAR testing is mandatory for portable devices to prove that they meet FCC RF exposure limits. In order to measure this, a phantom head will be used to simulate the human head. During the test, the head worn device will be operating at its highest power levels while simulating the way a human user would use the product. While in this configuration, a probe mounted on a robotic arm measures the RF energy that is absorbed in the simulated tissue in the SAM phantom and/or flat phantom. In order for a manufacturer to design a device meeting the regulatory requirement, during initial design and testing, head phantom shall be considered. If a device is designed for free space, testing with head phantom would impact the device radiation performance and would also impact the RF disposure test

5 Use Cases

With healthcare transforming from traditional medicine into a patient-centric model, VR/AR technologies along with tablet devices and wearable devices have the potential to generate rich sets of data, making patients and wider consumers with the access of care, moving away from patients having to visit doctors in person.

AR and VR tablets, glasses or headsets can enable field service applications with easy access in an immersive format that includes 3D illustrations, video-driven instructions, and real-time feedback. These technologies can replace bulky operator manuals, handheld devices or connected to an in-house technician if needed.

AR and VR based devices boost field technician's efficiencies in offering field services.

Other applications such as smart glasses along with Bluetooth hand scanner can offer AR warehousing solutions with order picking, goods sorting, inventory control, monitoring and many others.

5.1 3GPP Use Cases mapped by Device Type

The following 3GPP specifications map the use cases by XR device type.

- 00 - Support of 5G glass-type Augmented Reality / Mixed Reality (AR/MR) devices
- 3GPP TR26.918 - Support of 5G Virtual Reality devices

<u>The Appendix maps each of the use cases listed in the above 3GPP specifications by XR device type:</u>

- Virtual Reality Head Mounted Display (VR HMD)
- Augmented Reality Glasses (AR Glasses)
- Extended Reality Head Mounted Display (XR HMD)

5.2 Market Segment Use Cases identified by AT&T Marketing

Following is a list of the Use Cases identified by AT&T Marketing for specific market segments.

The top Use Cases are in the Media and Entertainment market segment.

Market Segment	Use Cases

Media and Entertainment	· Experience Centres · E-Games · Advertising and Immersive Marketing · New media / Social Media Channels
Field Worker	· Improved Diagnostics · Remote Expert Support · Agriculture Efficiency
Logistics	· Guided Stock Picking · Inventory Management · Training Content
Manufacturing	· Improved Product Design · Reduced Assembly Time · Decreased Error Rates for Component Assembly · Telepresence and Remote-Control Machinery · High Risk and Cost Training Collaboration
Public Safety and Law Enforcement	· Facial Recognition · Protocol Checklists · Public Safety Scanning for high body temperatures · Team Training and Simulation
Health Care	· Surgery and Procedures · Practitioner Training · Real-time patient data · Data visualization · Rehabilitation and Pain Management

5.3 *AT&T Marketing – XR Applications and Developers Ecosystem*

AT&T Consumer Mobility is engaging with the XR ecosystem in multiple ways.

AT&T works with partners on projects that support mostly marketing experiences. Some of these partners have included Nexus Studios, Meta/Facebook, Qualcomm, Ericsson, Digital Nation Entertainment, and others. These are mostly event and time bound in support of specific campaigns, but they not operating at scale across the AT&T 5G network and the AT&T customer base.

To achieve scale for developers, developers need consistent tools that allow them to gain the benefits of 5G without requiring them to do custom integrations with every mobile operator their customers would connect to. With over 800 mobile operators worldwide, the resources and complexity of integrating with each of them in a custom way would be highly prohibitive. For this reason, AT&T does not have, nor is planning, to build a proprietary developer platform to support XR. To solve this dilemma, AT&T is working with leading operating systems to integrate 5G performance features that offer developers a single method by accessing operating system APIs, and the smartphone operating systems will handle the heavy work of integrating with mobile network operators.

In the meantime, there do not appear to be any API's available which would make it easy for application developers to confirm if their applications are using a 5G connection or what type of 5G connection they are using.

The Smart Phone OS needs to be able to detect the capabilities of the 5G connection and be able to scale experiences accordingly.

AT&T Marketing is working on Developer API's for network performance with the Smart Phone OS providers. These APIs would be accessed by the developer through the APIs on the Smart Phone.

The Android OS provides these 5G API's:

https://developer.android.com/about/versions/11/features/5g#detectionhttps://developer.android.com/about/versions/11/features/5g#detection

AT&T is also working with the XR ecosystem, albeit indirectly, by partnering with prominent cloud providers to enable high performance connectivity between the AT&T network and these cloud data centres, which many XR developers will deploy applications on.

AT&T will continue to engage with the XR ecosystem to find mutually beneficial opportunities and may change its plans as we learn and discover new opportunities.

6 XR Device Technical Specifications

The Appendix includes a comprehensive list of the device technical specifications by device type (VR HMD, AR Glasses, XR HMD).

The Appendix includes definitions for each of these technical specifications.

A snapshot of the key technical specifications for XR devices is below:

- Modem Size
- Processing Speed
- Battery Size
- Maximum Power
- Battery Drain
- Maximum Weight
- Video rendering – persistence duty, display refresh, spatial resolution, offload to Cloud

- Display
- Optics – field of view, eye box, calibration, depth perception
- Connectivity (Wi-Fi, 5G, USB)
- Degrees of Freedom
- Tracking – camera, sensor, inside-out, outside-in, tracking accuracy, space, frequency
- Latency – motion to photon, pose to render to photon, interaction delay for games
- Streaming RTT from the Cloud

7 XR Chipset Roadmap

Modem chipset makers are expanding their modem support from eMBB to URLLC applications by adding new features and functionalities to the current modem chipsets. Broadband data throughput seems to be enough to meet XR device requirements. The focus is more on the other aspects of XR requirements, especially the requirements related to end to end (E2E) latency and reliability.

3GPP standards already provided some mechanisms to reduce round trip delay for message exchange between XR devices and server platforms, such as small slot, bandwidth part (BWP), etc. In addition, the flexibility of the standards also opens ways to further latency reduction efforts. The followings are some examples proposed by modem chipset makers:

- Using wider subcarrier spacing (SCS) to reduce time slot duration: e.g., increasing SCS from 15KHz to 30MHz will cut time slot duration by half (from 1ms to 0.5ms).
- Modify TDD pattern to make downlink and uplink duration more symmetric to decrease round trip delay. The current widely adopted TDD pattern is DDDSU (D for downlink slot, U for uplink slot, and S for switch slot), which is 4;1 for downlink vs. uplink. The TDD pattern can be adjusted to DS, DSU, or DDSUU to arrange more balanced resources for downlink and uplink.

Qualcomm already had two generations of modem chipsets for XR applications based on its Snapdragon 5G modems by incorporating functionalities and technologies to guarantee latency, reliability, and quality of services for XR requirements.

MediaTek is planning to add URLLC essentials to its M80 modem chip to support XR applications.

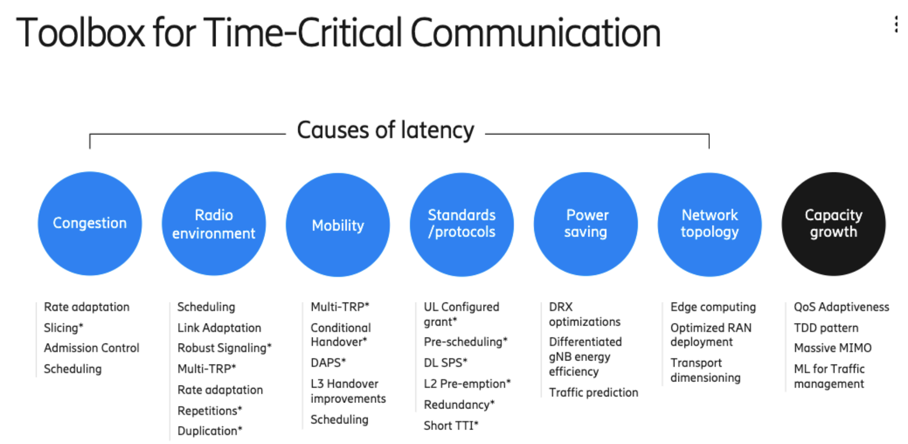
8 XR Device Network Requirements

Following is a list of the critical 5G Network Requirements mapped by XR device type (VR HMD, AR Glasses, XR HMD).

5G Network Requirements	VR HMD	AR Glasses	XR HMD
Latency - Budget	9-13 ms	TBD	TBD
Latency - RAN-DU	< 2 ms	TBD	TBD
Latency - Transport	< 5 ms	TBD	TBD
Latency - User Plane	< 3 ms	TBD	TBD
Latency - App Edge	< 7 ms	TBD	TBD
Cloud Edge Connectivity	Yes	Yes	Yes
Cloud Edge Server	Yes	Yes	Yes
Jitter	TBD	TBD	TBD
Transport RTT on 5G	< 20 ms	TBD	< 10ms
Streaming Frame Rate (fps)	TBD	TBD	TBD
Streaming bandwidth (MPS)	30-100 (DL)	30-100 (DL)	30-100 (DL)
MTU Size	1430 bytes	1430 bytes	1430 bytes
HARQ Retransmission Rate	TBD	TBD	TBD
RLC	UM	TBD	UM

UDP Support in RAN	TBD	TBD	TBD
Accurate Position Location	1m	1m	1m
mobility –ubiquitous coverage	Yes	Yes	Yes
security – private routing	Yes	Yes	Yes
performance – network slicing	Dedicated	Dedicated	Dedicated

The following drawing identifies the critical 5G network features needed to support the XR devices.



The above critical 5G network features are discussed in the following sections.

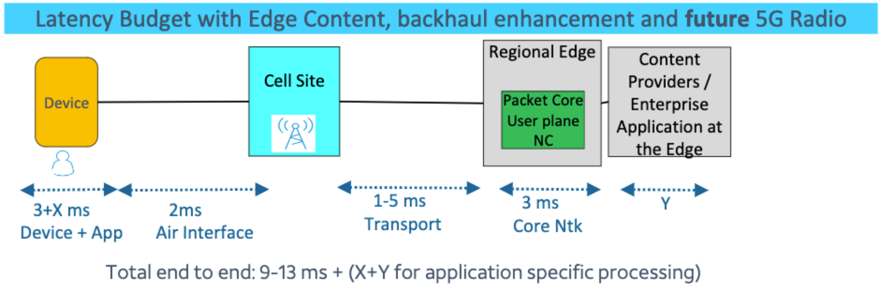
8.1 Latency

The transport network component supporting these device types includes these components:

1. Over-the-air (5G)
2. Mobile Network (Edge or PGW)

The content rendering component includes the Server and Client used by the device type.

Both components 'network' related delay and "server/client" delay comprise the total round-trip time.

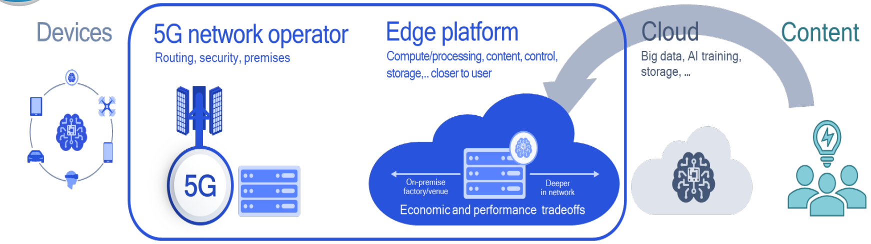


A total round trip time requirement of less than 20 ms applies to a VR HMD device and less than 10 ms to an AR HMD.

Round Trip Latency (E2E) in the range of 10 ms to 20 ms is critical to support the XR devices.

8.2 Edge computing

As summarized in previous section, E2E latency is sum of individual latency contributions from RAN, core, transport as well as device. For local network deployment with networking functionalities and XR applications hosted on premises, transport latency could be negligible. If not local network, the edge deployment of 5G core network and application are key to reduce the transport latency between the application and RAN. For network service providers, the edge can be in structures like legacy central offices, mobile base station equipment huts or even outdoor ruggedized street cabinets. In private enterprise networks, edge computing resources can be located on the customer's premises for security and very low latency. Also, the edge computing deployment allows the processing that would take place on XR device to now occur in the cloud. This significantly lowers the energy and battery demand in XR devices.



Dedicated EDGE Cloud-based Service architectures are critical to support the XR devices.

8.3 Network slicing

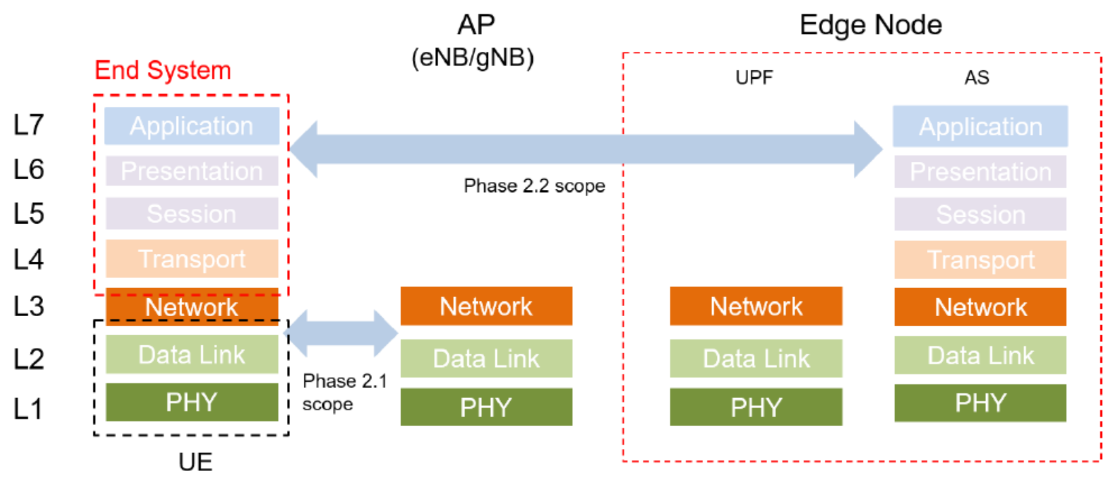
Network slicing is the embodiment of the concept of running multiple logical networks as virtually independent operations on a common physical infrastructure in an efficient and economical way. 5G networks, in combination with network slicing, can provide connectivity and data processing tailored to specific application requirements that adhere to a Service Level Agreement (SLA). Specific slicing can be configured for XR applications to meet requirements such as guaranteed data rate, latency, reliability, and security. Network slicing and radio resource partitioning together with admission control and latency optimized scheduling are important tools for reserving network resources for time-critical services like XR and avoiding congestion-related delays.

A URLLC type of slice meeting all XR requirements will be configured and reserved over 5G NR networks. The XR network slice with guaranteed XR service quality shares the same physical 5G NR connections with other applications.

A dedicated 5G network slice with guaranteed quality parameters is critical to support the XR devices.

8.4 Reliability

E2E system is a combination of the 3GPP system and a non-3GPP system, hence its performance is influenced by both these elements. The 3GPP domain, in fact, includes the signal path from the layer 2/3 interface on the UE to the layer 2/3 interface on the UPF, whereas, as defined above, the considered E2E network includes higher layers on the end system side, as well as all the layers on the AS side.



E2E reliability is the probability of correctly decoding an application layer packet at the receiver within the packet delay bound. Packets that arrive after the packet delay bound and packets that are lost or erroneous are considered as errors. The following table provides target E2E reliability for AR/VR type of applications.

Examples of Use Cases	Payload	Target E2E Reliability	Target E2E Latency
Data-rich applications for media and entertainment such as, e.g., Augmented Reality, Virtual Reality, collaborative gaming, etc. This is a use case that requires fast and reliable transfers of large payloads	1500 Bytes	99.90%	10.5 - 12ms

E2E reliability at 99.90% is critical to support the XR devices.

8.5 QoS/QCI

3GPP specifies several standardized 5G QoS Identifiers (5QIs) in TS 23.501 for services that are assumed to be frequently used and thus benefit from optimized signalling by using standardized QoS characteristics. Many of these 5QIs can support XR traffic that does not require low latencies.

Specifically, traffic from XR streaming applications in a device-based architecture can tolerate higher latencies, and can be supported by 5QIs 4, 6,8,9, all of which can support non-conversational video (buffered streaming) at a Packet Delay Budget (PDB) of 300 ms.

Traffic from the real-time 3D communication use case of XR requires lower latencies and can be supported by 5QI of two with a PDB of 150 ms.

Traffic from generalized XR architecture will require lower latencies and can be supported by 5QI of 80 with a PDB of 10 ms but without a guarantee on the bitrates (Non-GBR). Additional sets of standardized 5QIs for guaranteed bit-rate operation at low latencies can be expected in future 5G releases as the generalized XR architectures mature.

Recommendation to AT&T teams include separating the XR traffic from best effort eMBB traffic using the 5G QoS framework with optimized QoS flows.

The use of 5G QoS Identifiers on the AT&T network are critical to XR devices.

8.6 APN

Need to evaluate a dedicated APN for the XR devices which will contribute to the low latencies needed with “fast lanes” through the 5G network to the EDGE servers.

8.7 Network MTU

Need to evaluate if the AT&T and FirstNet networks need to use lower MTU requirements unique to the XR devices.

8.8 Power consumption

Power consumption is one problem that would limit how an AR/VR device can be used due to the need to frequently recharged or replace the battery in these devices. Fortunately, recent advancements in lower power consumption technology are changing what’s possible for the future of AR/VR devices. Since batteries are usually what take up a majority of the space within an AR/VR device, its size is commonly compromised in favour of sleek form factor. The advanced applications of AR/VR devices are the functions that would require more power consumption. While for certain type of AR/VR devices, idle-mode power consumption is critical. It is extremely important for 5G, which is much worse than LTE due to sparse synchronization and measurement resources. At the same time, in NR there is much increased wakeup energy overhead due to distributive SS bursts.

Extremely low battery consumption rates are critical for the XR devices.

8.9 Frequency bands for XR

AT&T currently doesn't plan to restrict XR services on any specific frequency band(s).

Below table summarizes the pros and cons of XR running on different categories of 5G frequency bands.

Frequency Bands	Technical Merits	Challenges
FR1 FDD (i.e., n5)	Excellent coverage	Limited capacity, not suitable for bandwidth hungry high data rate applications
FR1 TDD (i.e., n77)	Wide bandwidth availability and good coverage Stringent TDD coexistence requirement	Latency performance dominated by TDD configuration
FR2 TDD (i.e., n260)	Shortest TTI with wider bandwidth Relatively relax TDD coexistence requirement	Higher power consumption vs FR1 options Lack of coverage continuity and lower reliability due to blockage problem

8.10 Throughput expectations

XR connectivity requirements depend on the level of split architecture and the targeted QoE, leading to a wide range of bit rates and bounded latency requirements. The following table shows downlink and uplink data throughput requirements.

Use Cases	**DL Bit Rates (Mbps)**	**UL Bit Rates (Mbps)**
Cloud Gaming	8 - 30	~0.3
VR	30 – 100	< 3
AR	2 – 60	2 – 20

The maximum downlink bite rate is 100Mbps and maximum uplink bit rate is 20Mbps, respectively.

To meet the objectives, downlink FR1 FDD 3CA or 1 FDD + 1 TDD 2CA needs to be supported. FR1 1 FDD + 1 TDD configuration is more preferrable because of wider bandwidth and shorter time slot duration (30KHz SCS).

For urban and indoor environments, FR2 band (up to 800MHz) can also be used to enhance the guaranteed bits rate.

Downlink FR1 FDD 3CA or 1 FDD + 1 TDD 2CA is critical to support XR devices.

8.11 5G Accurate Positioning

Mobile Carriers are highly active in navigation and have an advantage over OTT players such as Google by leveraging 5G Accurate Positioning. This has more accurate positioning than GPS because it can provide lane-level guidance for drivers. It can also work indoors, giving a further advantage over GPS-based mapping.

5G Accurate Positioning can cover many items from Wi-Fi/BT/UWB indoor location based on sensors to use of 3GPP R16/R17 high accuracy positioning.

The initial features for 5G Accurate Positioning that are being developed on the AT&T LMF is MC-RTT/UL-AoA. Qualcomm has demonstrated 1m accuracy in this technology already. AT&T plans to present this requirement in the April 2022 TAM discussion.

AT&T's biggest impediment to 5G Accurate Positioning in the United States is that at this time it has been very difficult to get the AT&T RAN OEMs to include the capability in their development roadmaps, since the FCC at this time has not mandated higher accuracies for positions.

AT&T is still in discussions with RAN OEMs to implement this capability in the 2023 timeline.

5G Accurate Positioning is a critical feature needed to support the XR devices.

8.12 Mobility

Connection to Wi-Fi alone on legacy XR devices lacks ubiquitous coverage and mobility.

XR devices with 5G connectivity can provide seamless mobility.

Either stationary, pedestrian mobility or vehicular speed mobility, at least for now we don't expect any fundamental differences from XR mobility features required than those on mobile devices.

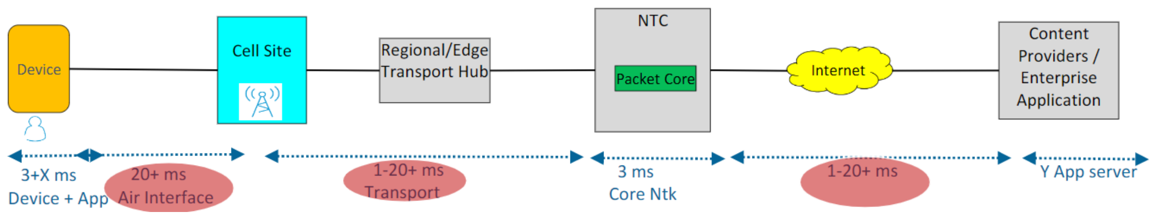
To better handle the time critical services nature of XR, the future network evolution in RAN vendors' roadmap to add NR mobility enhancements can also benefit XR devices to improve robustness and end user performance, such as multiple transmission reception points (multi-TRPs), dual active protocol stack (DAPS) handover and conditional handover.

5G Seamless Mobility is a critical feature needed to support the XR devices.

9 XR Device Test and Measurement Methodology

The dynamic acuity of AR and VR devices require many features to be measured so that the performance of the device and user experiences can be guaranteed. A comprehensive testing strategy would include functional testing, usability testing hardware testing and immersive testing. Tracking objects in real time is one of the important KPIs for AR/VR devices, such as tracking accuracy, tracking space and tracking frequency. To simulate the user's perception more accurately, the 6DoF tracking mode is required. The latency requirement for the overall end-to-end chain such as Motion-to-Photon latency in VR is commonly targeted at less than 20ms. Pose-to-render-to-photon latency in VR is aimed at 50ms to avoid wrongly rendered content. However, in AR the requirement is even stricter as visual changes are not only triggered by the motion of the user but also by any lighting change or natural object movement in the surrounding world.

To accommodate these requirements, the overall latency on mobile network chain needs to be carefully designed and tested.



To evaluate the over-the-air performance of XR devices, the device performance shall be measured with the device in its usage scenario.

For example, XR headsets shall be measured with a phantom head. XR watches shall be measured with a wrist phantom.

Battery performance of a XR device is equally essential. XR devices shall be transmitting at its peak data rate and maximum output power while battery time can be evaluated accurately.

10 Standards and Future XR Technologies

10.1 3GPP (from Release 15 to Release 18 – target to complete Release 18 in early 2024)

XR was considered by 3GPP as a key 5G use case since its inception. 5G connected XR and cloud gaming devices are anticipated to proliferate in years to come. To structure the work on cellular network and XR, 3GPP launched a feasibility study to identify use cases, technologies and gaps that need specifications for interoperable services even before 5G specs became available.

TR 22.891 "Feasibility Study on New Services and Markets Technology" contains around 70 use cases that led to the definition of the 5G system, many of these use cases envisioned Virtual Reality or Augmented Reality.

Subsequently, 3GPP Release 15 of 5G has been standardized incorporating XR as one of the use cases. 3GPP also conducted dedicated XR (specifically on VR) use cases study from Rel-15 under the TR26.918 "VR media services over 3GPP" such as 3D messaging, immersive 6DoF, immersive online gaming, remote assistance, real-time 3D communication, online shopping, and holographic communication, etc.

The actual study of XR over 5G started from Rel-16. TR26.928 discussed many XR use cases in detail in the extended reality tethering to 5G network and listed the high level XR functions and architecture in 5G network. While XR presents a set of attractive use cases for 5G, they also impose a set of challenges for NR that needs to be studied and potentially addressed.

Therefore, in Release 17, 3GPP has conducted an evaluation study on XR to assess their performance when connected by 5G under the study item "study on XR evaluations for NR".

Based on the results of above study items, Release 18 included enhancements to better support XR and cloud gaming devices in NR networks.

The traffic generated in XR and cloud gaming use cases is often quasi-periodic and requires high data rates and bounded latency simultaneously. To efficiently serve such type of traffic, 3GPP will investigate resource allocation and scheduling mechanisms that can improve capacity for XR and cloud gaming devices. Since many XR and cloud gaming devices have limited battery power, Release 18 will also study UE power-saving techniques to accommodate XR and cloud gaming service characteristics. Besides, 3GPP will investigate how to make RAN more XR-aware, including identifying what application information is beneficial for RAN to be aware of and how to utilize the information in RAN to handle XR and cloud gaming traffic. The Rel-18 work item "study on XR enhancements for NR" includes below items, to be completed in early 2024.

Objectives on XR-awareness in RAN (RAN2):

- Study and identify the XR traffic (both UL and DL) characteristics, QoS metrics, and application layer attributes beneficial for the gNB to be aware of.
- Study how the above information aids XR-specific traffic handling.

Objectives on XR-specific Power Saving (RAN1, RAN2):

- Study XR specific power saving techniques to accommodate XR service characteristics (periodicity, multiple flows, jitter, latency, reliability, etc...). Focus is on the following techniques:
    - C-DRX enhancement.
    - PDCCH monitoring enhancement.

Objectives on XR-specific capacity improvements (RAN1, RAN2):

- Study mechanisms that provide more efficient resource allocation and scheduling for XR service characteristics (periodicity, multiple flows, jitter, latency, reliability, etc…). Focus is on the following mechanisms:
    - SPS and CG enhancements
    - Dynamic scheduling/grant enhancements.

Planned Release 18 enhancements including efficient resource allocation, dynamic scheduling mechanisms, UE power saving techniques, and XR RAN awareness are critical for XR devices.

10.2 Other standards and open-source efforts

Besides the radio and service technology to enable standards based XR being discussed in 3GPP specs, there are many Research & Development efforts to improve compression algorithms for audio and video data generated from XR devices.

Many XR devices are equipped with more than one camera. Several compression techniques have been proposed for inertial measurement unit (IMU) data, such as delta encoding, linear extrapolation, second- to fifth-order polynomial regression and spline extrapolation.

There are numerous techniques for compressing 3D point cloud generated by LiDAR sensors.

ISO/MPEG currently has two tracks for point cloud compression standardization under development. These are Video-based Point Cloud Compression (V-PCC) and Geometry Based Point Cloud Compression (G-PCC). LiDAR is covered in the MPEG G-PCC track. The edge-rendered video and audio content is encoded into video and audio streams and transmitted to the device along with the rendering mesh data.

There are also many XR initiatives led by industry forums. One example is GSMA: The GSMA 5G Cloud XR effort aims to "bring together Cloud based technologies and XR to deliver superior experiences that revolutionize the consumption of content in both the consumer and the enterprise sectors." The initiative focuses on the following topics, to help Operators tackle the challenges of this new service:

- Identify the key use cases in Cloud XR
- Investigate value chain, stakeholders, and business models
- Share case studies and best implementation practices
- Define a recommended service architecture to accommodate 5G Cloud based services

Standards defined compression algorithms for audio and video data streams and 5G Cloud based service architectures are critical for XR devices.

11 Device Architecture Recommendations & Next Steps

Following are the recommendations and next steps for work to be initiated during 2Q 2022:

- Develop an 13289 specific to XR devices which maps the applicable 13340 requirements and identifies new design requirements needed to support the XR devices
- Need to map each of the device technical specifications listed in the Appendix with a 5G network component (I.e., tracking, latency, video rendering, connectivity, streaming, camera)
- Pursue technical collaboration/partnerships with diverse companies in the XR space (OS vendors, Market Segment consumers, XR device vendors, application developers, content providers) on the XR device technical specifications and required 5G network capabilities

    - Verizon has already announced during 2022 Investor Day that they will partner with Meta (Facebook) to determine network requirements to support XR cloud rendering and low latency streaming, and measure the impact for edge computing on key performance metrics for metaverse optimized performance
    - AT&T needs to pursue a technical partnership with a key player in the XR space to accelerate the network and XR device readiness through trials, use cases and device testing
- Develop XR device testing capabilities – both captive and field, as well as automation – which are based on XR experience-based testing criteria
- Provide guidance to AT&T Marketing on the offering of AT&T XR devices (separately from smartphone, or bundled in with devices which do not manufacture a corresponding headset), XR specific rate plans, and bundling of devices, rate plans, and content for the specific segments
- Provide planning guidance to AT&T Network for the engineering and provisioning needed to support the unique requirements of XR devices (latency budgets, slicing, QoS, edge computing, bandwidth, etc.)
- Provide planning guidance to AT&T Network on the up-and-coming 3GPP Release roadmap for XR devices
- Execute pilot testing projects with early XR device samples (I.e., AR Glasses) and Cloud servers, as needed to develop experience-based testing capabilities

12 Conclusions

Widespread adoption of XR devices has previously been hindered by issues such as lack of mobility, cost, limited processing power, battery life, etc.

The ongoing 5G rollouts by AT&T could potentially enable the realization of XR on a large scale.

The main objective of this White Paper is to prepare us for the 5G XR devices on the horizon, identify the business drivers to align with AT&T's 5G use cases and to ensure the key technical requirements are aligned with AT&T cross functional teams and the ecosystem.

Following this objective, we first analysed the industry trend and competitors' landscape, we then summarized the XR use cases, device form factors and challenges. From the end-to-end perspective, we performed the XR case studies, listed the required device & network requirements and demonstrated the transformative potential of XR on 5G network.

Importantly, this work provides the planning guidance on XR device requirement development, network development, and XR device test strategy planning.

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14 Appendix

14.1 3GPP Use Cases

3GPP Use Cases	VR HMD	AR Glasses	XR HMD
3D Image Messaging	Yes	Yes	Yes
AR Sharing using See Through and SLAM	No	Yes	Yes
Real Time 3D Communications	Yes	Yes	Yes
AR Guided Assistant at Remote Location	No	Yes	Yes
Police Critical Mission with AR	No	Yes	Yes
Online shopping from catalogue (See Through and SLAM)	No	Yes	Yes
Real time communication with shop assistant (See Through and SLAM)	No	Yes	Yes
360-degree conference meeting	Yes	Yes	Yes
XR Meeting	Yes	Yes	Yes
Convention / Poster Session (Join Teams/Zoom 2D session where poser presentation is included	Yes	Yes	Yes
AR animated Avatar calls	Yes	Yes	Yes
AR avatar multi-party calls	Yes	Yes	Yes
Front facing video multi party calling while walking	No	Yes	Yes
AR Streaming with localization registry (See Through and SLAM)	No	Yes	Yes
5G Shared Spatial Data (SLAM)	No	Yes	Yes

AR Remote cooperation	No	Yes	Yes
AR Remote advertising	Yes	Yes	Yes
Streaming of volumetric video for glass type MR devices	Yes	Yes	Yes
AR IoT (see through and camera to locate IoT device)	No	Yes	Yes
AR Gaming	No	Yes	Yes
Shared AR Conferencing Experience (See Through and SLAM)	No	Yes	Yes
Event broadcast/multicast	Yes	No	Yes
VR streaming	Yes	No	Yes
Distributing 360 A/V content library	Yes	No	Yes
Live services consumed on HMD	Yes	No	Yes
Social TV and VR	Yes	No	Yes
Cinematic VR	Yes	No	Yes
Learning application	Yes	No	Yes
VR calls	Yes	No	Yes
User generated VR	Yes	No	Yes
Virtual world communication	Yes	No	Yes
HMD-based legacy content consumption	Yes	No	Yes
Highlight Region(s) in VR video	Yes	No	Yes

14.2 Device Technical Specifications by Device Type

Device Technical Specifications	VR HMD	AR Glasses	XR HMD
Modem Size	TBD	TBD	TBD
Processing Speed - UE	TBD	TBD	TBD
Processing Speed - APP	TBD	TBD	TBD
Battery Size	TBD	TBD	TBD
Maximum Power	3-7 Watts	0.5-2 Watts	TBD
Battery Drain	TBD	TBD	TBD
Maximum Weight	100 grams	70 grams	TBD
Video rendering - persistence duty time	turn pixels off/on every 3 sec	TBD	turn pixels off/on every 3 sec
Video rendering - display refresh rate	90 Hertz	TBD	120 Hertz
Video rendering - spatial resolution	4K x 4K	TBD	4K x 4K
Video rendering - offload to Cloud	TBD	TBD	TBD
Chipset	TBD	TBD	TBD
Display (pixel, fps)	70-90 fps	TBD	
Optics - Field of view	100-110 FOV	TBD	40x40 FOVV
Optics - Eye box	20mm	TBD	20mm

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Optics - Calibration	correction for distortion and chromatic aberration that exactly matches the lens characteristics	TBD	correction for distortion and chromatic aberration that exactly matches the lens characteristics
Optics - Depth Perception	Avoid vergence and accommodation conflict (VAC) for accommodation at fixed same distance (e.g. 2m)	TBD	Avoid vergence and accommodation conflict (VAC) for accommodation at fixed same distance (e.g. 2m)
Connectivity (WiFi, Cellular, USB)	Yes	Yes	Yes
Degrees of Freedom	6 DoF	TBD	6 DoF
Tracking - Camera	Yes	Yes	Yes
Tracking - Sensor	Yes	Yes	Yes
Tracking - Inside-out/outside-in	Yes	Yes	Yes
Tracking - Translational Tracking Accuracy	< 1 centimeter	TBD	< 1 centimeter
Tracking - Rotational Tracking Accuracy	quarter degree	TBD	quarter degree
Tracking - Space	Yes	Yes	Yes
Tracking - Frequency	> 1000 Hertz	TBD	> 1000 Hertz
Latency - motion to photon	< 20 ms	TBD	< 10 ms
Latency - pose to render to photon	50 ms	TBD	50 ms
Latency - interaction delay for games	1000 ms	TBD	N/A
Head Tracking API support	Yes	Yes	Yes

Graphics API support	Yes	Yes	Yes
Streaming RTT from the Cloud	< 60 ms	< 60 ms	< 60 ms

14.3 Key Definitions

The following URL specifies key definitions for the technical requirements referenced in this White Paper.

https://unity.com/how-to/what-is-xr-glossary

Following are some key definitions:

360 Video

Frequently called "spherical videos" or "immersive videos", 360 videos are video recordings where a view in multiple directions is recorded simultaneously. They are typically shot using a specialist omnidirectional camera, or a collection of separate, connected cameras mounted as a spherical array. 360 videos can be live action (cinematography or videography that does not use animation), animated (captured from a 3D scene), or a mix of computer generated graphics and live action. After being prepared for display via a technology such as a 3D game engine, 360 videos are then viewed by the user in a headset.

360 videos can be non-interactive or interactive. Non-interactive 360 videos are experiences where the viewer cannot influence the viewing experience outside of perhaps pausing the video or moving their head to take in different "camera angles". Interactive 360 videos are experiences where the viewer can interact with the UI or other interactable elements using gaze or a controller.

Augmented Reality (AR)

Augmented reality is the overlaying of digitally created content on top of the real world. Augmented reality – or 'AR' – allows the user to interact with both the real world and digital elements or augmentations. AR can be offered to users via headsets like Microsoft's HoloLens, or through the video camera of a smartphone.

In both practical and experimental implementations, augmented reality can also replace or diminish the user's perception of reality. This altered perception could include simulation of an ocular condition for medical training purposes, or gradual obstruction of reality to introduce a game world. It is worth noting that there is a point when augmented reality and virtual reality likely merge or overlap.

Field-of-View (FOV)

The field-of-view is all that you can see while looking straight ahead. FOV is the extent of your natural vision, both in reality and in MX content. The average human field-of-view is approximately 200 degrees.

Frames-Per-Second (FPS)

"Frames-Per-Second" – or FPS for short – refers to the number of times an image on the screen is refreshed each second.

Head Tracking

Using various approaches, head tracking monitors and tracks the position and movements of a given user's head and neck, offering a potential means for input and interaction.

For example, if the user's neck and head are slightly inclined to one side, with head tracking enabled what they see in the HMD could shift to the same angle. A user can equally stretch their neck to look around or up and over something. That same user could make a movement such as "looking at the floor" to activate a specific gameplay action.

Latency

Latency is the speed at which the virtual world reacts to a user's movement. A virtual world with high latency could be described as showing lag. As a simple rule, the less latency there is, the more comfortable a given experience will be. The rule of thumb is for latency to be sub 20 milliseconds. The lower the number of milliseconds, the better an experience will be.

Latency can also refer to the rate at which a virtual world updates for the user.

Mixed Reality (MR)

A mixed reality experience is one that seamlessly blends the user's real-world environment and digitally created content, where both environments can coexist and interact with each other. It can often be found in VR experiences and installations and can be understood to be a continuum on which pure VR and pure AR are both found. Comparable to Immersive Entertainment/Hyper-Reality.

Mixed reality has seen very broad usage as a marketing term, and many alternative definitions co-exist today, some encompassing AR experiences, or experiences that move back and forth between VR and AR. However, the definition above is increasingly emerging as the agreed meaning of the term.

Motion-to-Photon Latency

Motion-to-photon latency is the measure of time between when actual motion occurs in the real world and when the eye receives a photon from the HMD screen that reflects this change. Thanks to the extremely high speeds and rather short distances, it is very difficult to measure, but represents the total effectiveness of a VR system from a latency standpoint. Lay users sometimes describe this phenomenon under the same terms as “lag”.

Round Trip Time

Round Trip Time is:

= The time it takes to send a request from the client to a server

+ The time it takes the server to process the request

+ The time it takes the server to send a reply back to the client

Six Degrees of Freedom (6DOF)

A system that provides six degrees of freedom tracks an object’s position and rotation in three dimensions. The three positional axes combined with the three rotational axes total six “degrees” which can be freely controlled.

SLAM (Simultaneous Localization and Mapping)

Simultaneous localization and mapping are the process whereby a map is generated and updated by an agent – perhaps a vehicle – moving through that space, at the same time that such an agent is tracked in the space. There are many distinct approaches at present, and the technology is emerging as crucial to self-driving cars, domestic robots, and AR applications.

Virtual Reality

As virtual reality has evolved and found different uses in different sectors, several different definitions have emerged, most of which significantly overlap with one another. Discrepancies exist. The following elements, however, are near universal in framing what VR offers:

- Computer-generated stereo visuals which surround the user, entirely replacing the real-world environment around them. Many believe this definition rightly excludes 360 videos from true VR.

- Content is consumed and experienced from a viewer-centric perspective.
- Real-time user interaction within the virtual environment is possible, whether through detailed interactions, or simply being able to look around within the experience. Here the real-time element means response comes within a particular time interval that is specific to the application or field.

XR

Technology-mediated experiences that combine virtual and real-world environments and realities. Here the “X” can be seen as a placeholder for V(R), A(R), or M(R), though it also represents an undefined or variable quality/quantity. XR covers the hardware, software, methods, and experience that make virtual reality, mixed reality, augmented reality, cinematic reality and others a reality. Most definitions of XR encompass platforms and content where the user can take digital objects into reality, or, conversely, see physical objects as present in a digital scene.

XR experiences include those where users generate new forms of reality by bringing digital objects into the physical world and those that see the bringing physical world objects into the digital world.

XR is used as an umbrella term and is frequently used as a casual shorthand to group technologies such as VR, AR, and MR together.

14.4 Abbreviations

For the purposes of this White Paper, the abbreviations given in 3GPP TR 21.905 [1] and the following apply.
An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

5G	5th generation, the latest generation of cellular mobile communications
3GPP	3rd Generation Partnership Project
UL	Uplink
3DOF	3 Degrees of freedom
6DOF	6 Degrees of freedom
ACN	Ambisonic Channel Number
AOP	Acoustic Overload Point
BRIR	Binaural Room Impulse Response

CBA	Channel-Based Audio
CICP	Coding Independent Code Point
CMAF	Common Media Application Format
DASH	Dynamic Adaptive Streaming over HTTP
DAW	Digital Audio Workstation
EPG	Electronic Program Guide
ERP	Equirectangular projection
FOA	First Order Ambisonics
FOV	Field of view
HMD	Head Mounted Display
HOA	High Order Ambisonics
HRTF	Head-related transfer function
M2S	Motion to Sound
MBMS	Multimedia Broadcast Multicast Service
MDA	Multi-Dimensional Audio
mTSL	minimum Total System Latency
OBA	Object-Based Audio
OMAF	Omnidirectional Media Format
QoE	Quality of experience
SBA	Scene-Based Audio
SNR	Signal to Noise Ratio

SRM	Similarity Ring Metric
TV	TeleVision
UPF	User Plane Function
VR	Virtual Reality

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