

Immersive Content over 5G: A Feasibility Study for 360-degree Streaming in FWA Networks

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Abstract—The 5G New Radio (NR) ecosystem is engineered to support the rigorous Quality of Service (QoS) demands of Extended Reality (XR), necessitating high-bandwidth transmission and ultra-low latency. This paper evaluates the feasibility of an Over-The-Top (OTT) 360-degree video streaming system deployed over a real end-to-end (E2E) 5G infrastructure. The experimental testbed integrates an Insta360 ONE X camera for content acquisition, a private 5G core based on Open5GS, and srsRAN-powered gNodeBs (gNBs). Content is processed via a MediaMTX streaming server for protocol conversion and delivered to a Meta Quest 3 headset via Fixed Wireless Access (FWA). Performance evaluation focuses on uplink and downlink throughput, Round Trip Time (RTT), and jitter, supplemented by a Glass-to-Glass (G2G) latency assessment utilizing computer vision and Optical Character Recognition (OCR). Experimental results reveal an average uplink throughput of 5.761 Mbps, a downlink of 3.7 Mbps, and an average jitter of 29.37 ms. These findings confirm the system's ability to maintain 30 fps immersive streams, identifying the WebRTC/5G pipeline as a viable solution for latency-sensitive immersive services while highlighting protocol-specific bottlenecks in the capture stage.

Keywords—360 Video, FWA, WebRTC, 5G.

I. INTRODUCTION

The 5G network was conceived to satisfy requirements that extend beyond high transmission rates, thereby enabling emerging services such as Extended Reality (XR). XR is a broad term encompassing applications that seamlessly combine physical and digital environments into unified experiences. This technology spectrum ranges from fully immersive digital environments, as in Virtual Reality (VR), to Augmented Reality (AR), which enhances the physical world by overlaying virtual objects and contextual information, and further extends to Mixed Reality (MR), where physical and digital objects coexist and interact in real time. XR applications have found widespread adoption across diverse sectors,

including education [1], urban mobility [2], entertainment [3], tourism [4], commerce [5], industrial operations [6], and, notably, healthcare and well-being [7].

A promising XR application involves 360° video or panoramic imagery displayed on Head-Mounted Displays (HMDs) such as the Meta Quest 3. Content can be captured using dedicated 360° cameras (e.g., the Insta360, GoPro Max, and Ricoh Theta) as well as drones equipped with 360° capture capabilities. Once produced, this content can be published and consumed through platforms such as YouTube VR, Meta Quest TV, Vimeo 360, and Google Street View. Even without interacting with complex three-dimensional objects, 360° video streaming serves as an entry point into the XR ecosystem, enabling users to explore real, digital, or mixed environments simply by looking around.

Typically, VR head-mounted devices are connected via Wi-Fi, which constrains the user experience in terms of mobility. Cellular network connectivity is seldom adopted due to the stringent Quality of Service (QoS) requirements imposed by XR applications; for instance, commercial 4G networks may not achieve latencies below 20 ms [8], thereby compromising interactive XR services. Illustrative examples include Industry 4.0 applications, in which users remotely operate real-world equipment and where excessive latency can potentially lead to critical failures or accidents. To support such services, customized network slicing becomes essential, as it provides high data rates, low latency, and proper network isolation.

The XR market was valued at US\$ 142.39 billion in 2023, with growth projections reaching US\$ 1,069 billion by 2030 [9] and US\$ 2,127.81 billion by 2034 [10]. Such substantial investment reflects an expanding range of applications and use cases expected to emerge across the automotive, gaming, and entertainment sectors [9], [10]. These applications are highly sensitive to latency, motivating research efforts aimed at enabling efficient support for immersive experiences over 5G networks [9], [10].

This study presents an analysis of immersive Over-The-Top (OTT) video streaming over a real End-to-End (E2E) 5G infrastructure. The proposed architecture enables video transmission from an Insta360 ONE X camera to a smartphone connected to a gNB, which forwards the captured content to an open-source streaming server. Subsequently, the video is delivered to end users via a web browser using the Web Real-Time Communication (WebRTC) protocol. To consume the content, the streaming application is accessed through a Meta Quest 3 headset connected to a Fixed Wireless Access (FWA) device, which retrieves the content from the server through a second gNB.

This work presents a proof-of-concept implementation of a 360° video OTT streaming service deployed over an experimental E2E 5G infrastructure, illustrated in Fig. 1. The

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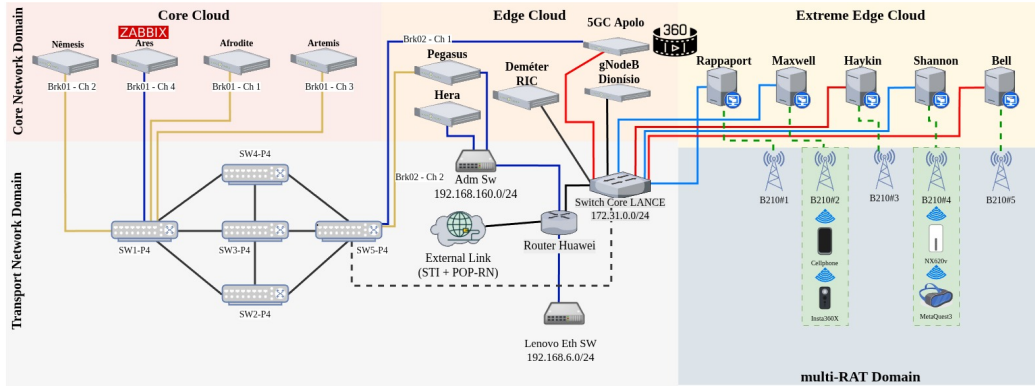


Fig. 1: 5G Testbed for Immersive OTT Streaming Feasibility Study.

proposed platform integrates open-source 5G technologies, VR devices, 360° cameras, and FWA to establish an environment suitable for developing and evaluating immersive applications. Furthermore, the study investigates monitoring mechanisms for assessing the performance of the provided services. The main contributions of this work are summarized as follows:

- Design and implementation of an E2E 5G testbed based on open-source technologies to support immersive applications.
- Integration of VR technologies, 360° cameras, and FWA within an experimental OTT streaming environment.
- Development of monitoring mechanisms for service performance assessment.
- Experimental evaluation of the proposed system over a real 5G infrastructure, considering throughput and latency as performance metrics.

II. RELATED WORKS

This section reviews the state of the art in XR for 360° video transmission over 5G networks, encompassing a quantitative study (Section II-A) and a qualitative analysis of related works (Section II-B).

A. Quantitative Evaluation

To assess the relevance of the topic, a quantitative study was conducted by analyzing the volume and evolution of publications on XR, particularly those associated with mobile network technologies. To this end, bibliometric data were collected from the Scopus database using the search terms presented in Table I. These terms were defined using the *AI Query Builder*, available within the platform, which enables the construction of more accurate queries aligned with the scope of this study. To capture recent developments in the field, the search was restricted to publications from 2015 to 2025.

TABLE I: Search Terms Used in the Quantitative Analysis.

Category	Terms Used	Search Fields
XR	XR, extended reality, VR, virtual reality, AR, augmented reality, mixed reality, immersive technology	Title, abstract, and keywords
Mobile Networks	5G, 6G, LTE, New Radio, NR, mobile network	Title, abstract, and keywords

The first result of the quantitative study concerns the annual number of scientific publications on XR, considering both

the overall body of research and studies involving cellular network technologies. As illustrated in Fig. 2, the scientific community has demonstrated growing interest in the field, which accumulated more than half a million publications over the 11-year analysis period. Nevertheless, research specifically addressing the integration of XR and cellular networks remains a relatively small fraction of the total, accounting for less than 3% of publications. This outcome is not unexpected, as mobile networks may still face significant limitations in satisfying the QoS requirements of XR applications, particularly given the existing constraints on 5G connectivity support for immersive devices.

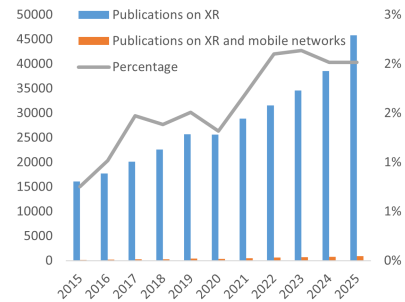


Fig. 2: Publications per year on XR and mobile networks.

Table II presents the research areas with the highest number of publications related to XR technologies. Although Computer Science accounts for the largest share of publications (21%), a broad range of disciplines has demonstrated interest in XR applications, including Engineering (16%), Medicine (10%), and Social Sciences (5%). These results indicate that, despite its origins in Computer Science, XR has evolved into a highly multidisciplinary research domain.

TABLE II: Percentage Distribution of XR Publications by Research Area.

Research Area	XR Publications	Percentage
Computer Science	127,209	21%
Engineering	96,611	16%
Medicine	57,670	10%
Physics and Astronomy	40,001	7%
Mathematics	35,694	6%
Social Sciences	32,231	5%
Materials Science	31,014	5%
Others	179,856	30%

B. Qualitative Evaluation

While quantitative analysis points to a growth in publications, the qualitative approach reveals the practical use of XR technology, highlighting real-time immersive transmissions. In Engineering, for example, XR applications enhance technical support and industrial maintenance [11], [12], enabling inspections and remote assistance through panoramic views. In Medicine, this technology enriches surgical training and clinical simulations [13], [14], allowing students to follow complex procedures as if they were in the operating room. Finally, in the Social Sciences, immersive transmissions support behavior and empathy studies by bringing individuals closer to different realities, transmitting real social contexts to VR headsets [15], [16].

Across various domains, the widespread deployment of XR services over mobile networks remains highly challenging due to the unstable nature of the wireless medium [17]. Some challenges of this deployment are analyzed in [18], which shows that the tested LTE and Wi-Fi networks cannot fully support multi-sensory links requiring sub-millisecond latency for control commands alongside high-resolution video feedback. Even with the transition to 5G New Radio (NR), the implementation of XR services is not without complications. The paper [19] indicates that XR performance does not scale linearly with the data rate and remains extremely sensitive to packet delay budgets. The uplink, specifically, often becomes a significant bottleneck when multiplexing frequent pose update packets from multiple users [19]. To bridge these gaps, the authors of [20] analyze technical barriers in 5G-Advanced (5G-A) and propose an overall system architecture focused on application-network coordination.

Within the realm of 5G immersive transmissions, research remains limited. The authors of [21] evaluate 360° video over 5G using HMDs, revealing that while 5G supports 4K resolution, measured latencies of approximately 72 ms still exceed the 20 ms threshold required for optimal immersion. While their study relies on the Dynamic Adaptive Streaming over HTTP (DASH) protocol, our work adopts WebRTC to target even lower interactivity delays. Complementing this analysis, the paper [22] demonstrates that integrating WebRTC with edge computing can reduce G2G latency to approximately 700 ms. However, while these works focus on native cellular or Wi-Fi connectivity, they do not address the connectivity gap of current commercial HMDs, such as the Meta Quest 3, which lack native 5G support. Our research distinguishes itself by implementing FWA as a primary bridge in an entirely open-source 5G infrastructure composed of Open5GS and srsRAN, providing a real-world prototyping environment that remains underexplored in the current literature.

III. EXPERIMENTAL SYSTEMS ARCHITECTURE

From the perspective of enabling an E2E 5G connection, a testbed was set up based on a private 5G network, in which all network components were connected to the mobile network. We are using Open5GS running on a server located at the Edge-Cloud (Apollo), connected to two radio stations running srsRAN (gNBs Shannon and Maxwell), where one serves as the connection for transferring the frame stream recorded by the 360° camera, and the other serves for consuming the streaming through the VR headset (see Fig. 1).

The transmission from the Insta360 ONE X took place over a Wi-Fi connection between the camera and a mobile phone,

which was enabled as a Wi-Fi access point with external connectivity via gNB Maxwell, as shown in Fig. 3. The video streaming packets were sent using the Real-Time Messaging Protocol (RTMP). The use of this legacy technology was due exclusively to the camera's lack of firmware support for more recent technologies.

Upon leaving Maxwell, the OTT application data travels to the 5G Core (5GC) through the transport network. Open-source and out-of-the-box tools, such as MediaMTX, were used to integrate the architecture components, receiving video via RTMP and delivering it via WebRTC.

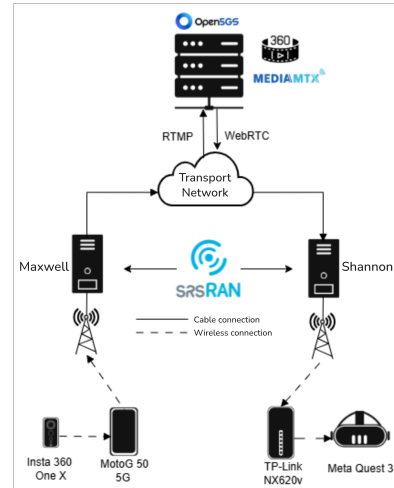


Fig. 3: 5G Architecture for XR operations support.

On the other end of the connection, to connect the Meta Quest 3 to 5G, it was necessary to rely on an FWA connected to gNB Shannon. The FWA (TP-Link NX620v) acts as a Wi-Fi access point with 5G connectivity and, since the headset does not natively support cellular connection, this component becomes essential for integrating all experiment elements into the 5G testbed.

Regarding processing and encoding, the video leaving the camera is delivered to the mobile phone encoded in H.264. Upon reaching the OTT server, the video is converted to RTSP with the aim of converting the audio to a format suitable for WebRTC (Advanced Audio Coding (AAC) to Opus). The audio and video codecs are extremely important in determining the maximum WebRTC bitrate, as dynamic adjustment may occur depending on the codec used [23]. It is explicit in the Opus RFC that bitrate adjustment exists between low (6 kbps) and high (510 kbps) rates [24], while for H.264 a maximum of 14 kbps was found in webRTC-internals with codec level 3.1, in accordance with what is defined by the ITU in [25].

Finally, it is worth emphasizing the configurations used in both gNBs: Multiple Input Multiple Output (MIMO) with 2 transmit antennas and 2 receive antennas, 256 Quadrature Amplitude Modulation (QAM), and 51 Physical Resource Blocks (PRBs). The gNBs were separated into two indoor environments to avoid co-channel interference.

IV. ASSESSMENT METHODOLOGY AND TEST CASES

For this study, real-time transmissions were conducted to collect throughput and latency metrics, with the aim of analyzing the performance of the private 5G network in delivering OTT live streaming.

To calculate throughput and latency, a 60-second OTT transmission was performed. For the throughput, the gNBs were monitored utilizing Zabbix. We used an in-house built monitoring software system responsible for collecting computational and network data [26], located on a server in the Core Cloud, as illustrated in Fig. 1.

A Glass-to-Glass (G2G) [22] methodology was used to measure the latency between the sender (Insta360 ONE X) and the video consumer (Meta Quest 3), measuring the One-Way-Delay (OWD) along the entire video packet pathway. To perform this measurement, video frames as shown in Fig. 4 were recorded using the Meta Quest 3 for subsequent offline image processing, comprising two key visual elements:

- ❶ Chronometer in the computer screen captured by the VR camera;
- ❷ 360° video consumed by the VR headset, showing the reception delay on the chronometer.

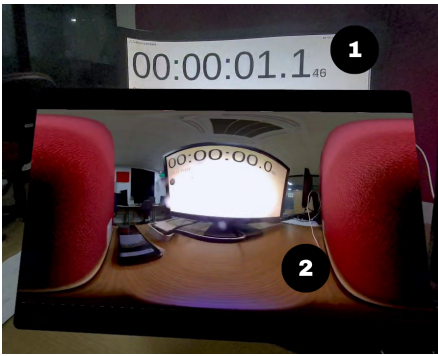


Fig. 4: Measurement of the G2G latency.

The extraction of chronometer values and the G2G latency calculation were performed using a Python script developed with the OpenCV and EasyOCR libraries. The search for chronometer regions is carried out using computer vision techniques, applying luminance intensity thresholding, morphological dilation, and contour detection to identify the two largest rectangular areas in the frames, thereby isolating the regions of interest (chronometers 1 and 2 in Fig. 4). To ensure the reading accuracy, the code applies a pipeline of dynamic adjustments on the image in case of OCR failure. Finally, the extracted times pass through a logical consistency validation based on temporal restrictions, with time samples exported to a CSV file, enabling a final delay tabulation.

Additionally, among the metrics provided by webRTC-internals, Round Trip Time (RTT) and Jitter were chosen, gathered over a 15-minute transmission and collected directly on the client using the native debugging tool of Chromium-based browsers, webRTC-internals (browsers built with the Chromium engine).

V. RESULTS AND DISCUSSIONS

Figs. 5 and 6 present the violin plot combined with the boxplot and the scatter plot of the throughput during the experiment. Fig. 5 (stream from the camera to the headset) shows that the central tendency of the uplink measurements at Maxwell was approximately 5.76 Mbps, while the downlink at Shannon was 3.73 Mbps. This difference in transmission rate is due to differences between the protocols, since RTMP uses TCP [27], whereas WebRTC uses RTP over UDP [23]. This implies a smaller packet header (lower overhead) and,

consequently, lower downlink throughput for the streaming service consumer, while also eliminating TCP retransmission overhead. It is possible to confirm in Fig. 6 the more dispersed signaling exchange between the headset and the Shannon gNB, certainly due to the WebRTC bitrate adaptation protocol.

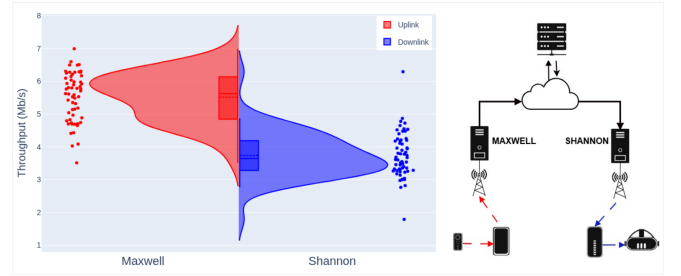


Fig. 5: Throughput of the gNBs (flow from the camera to the headset).

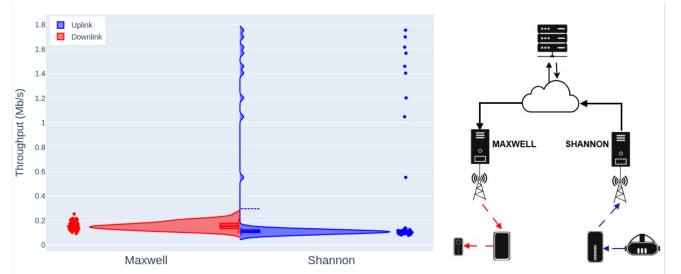


Fig. 6: Throughput of the gNBs (inverse flow).

The use of RTMP at the video output was necessary due to the wide support of this protocol by 360° cameras for video stream transmission [22]. On the server, the stream is converted to WebRTC, given its greater suitability and optimization for low-latency real-time multimedia communications [23].

As shown in Fig. 7, the RTT obtained from the WebRTC-internals data between the server and the headset averaged approximately 39.12 ms (estimated OWD of 19.56 ms), indicating WebRTC's capability to provide communication with controlled latency. Regarding the G2G OWD, shown in Fig. 8, the average delay was 1.27 s.

Consequently, the WebRTC transports protocol accounts for only a small fraction of the total G2G delay, indicating that the bottleneck lies elsewhere in the pipeline. One of the factors associated with this value is the delay introduced by RTMP on the video generation side, whose use directly impacts the end-to-end latency of the entire system [22].

In addition to the RTT, the service jitter is presented in Fig. 7. This metric plays an important role in QoS evaluation, since high delay variability can compromise transmission stability. The results obtained indicated an average jitter of approximately 29.37 ms, a value close to the 33.33 ms threshold for 30 fps transmissions without frame loss [28].

As part of the evaluations conducted in the experimental scenario, the use of the HTTP Live Streaming (HLS) protocol, developed by Apple, was also investigated due to its broad browser compatibility and ability to deliver high-quality video streams. However, the tests revealed a trade-off between quality and delay, since HLS introduced a significant increase in end-to-end latency. Given that the scenario already incorporates

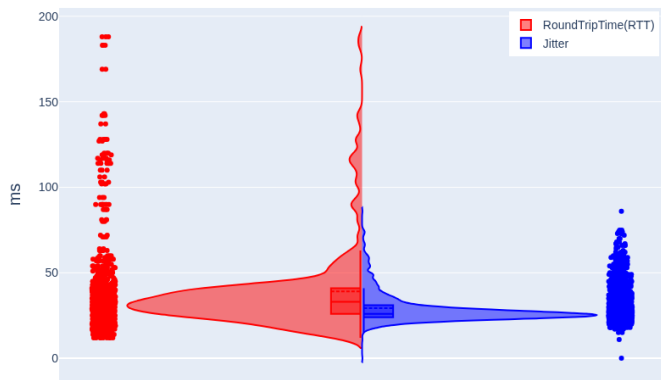


Fig. 7: RTT and jitter from webRTC-internals.

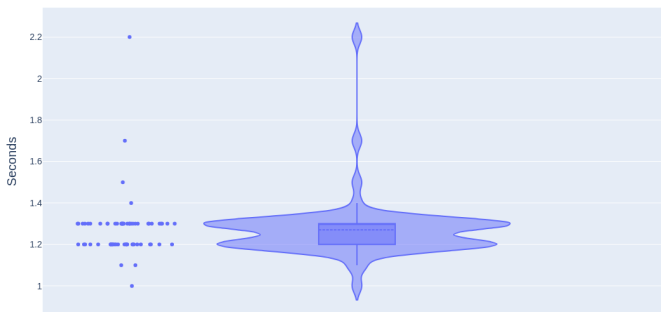


Fig. 8: OWD G2G measurement.

delay at the initial transmission stage due to the use of RTMP, adopting HLS resulted in average delays exceeding 10 s, rendering it unsuitable for real-time streaming applications.

VI. CONCLUSIONS

This work presents a feasibility study and a proof of concept of an OTT 360 video streaming system operating on a real E2E infrastructure. The research describes the implementation of an experimental testbed that integrates open-source technologies (such as Open5GS and srsRAN), immersive capture cameras, and Meta Quest 3 virtual reality headsets, connected via FWA. The central objective was to evaluate the capability of a private 5G network to meet the stringent throughput and latency requirements of XR applications.

The results indicated an average throughput of 5.76 Mbps on the uplink and 3.73 Mbps on the downlink, with a jitter of 29.37 ms, showing that WebRTC is compatible with 30 fps transmissions. However, the G2G OWD revealed an average of 1.27 s (higher than reported in the literature [22]), indicating that the use of the RTMP protocol in video capture is the main bottleneck for reducing total latency.

For future work, the focus will be on investigating internal network congestion and mitigating it by adjusting configuration parameters across the gNBs and the 5GC. It is also intended to analyze the impact of FWA on G2G delay in comparison to a future 5G native connection in the glasses, aiming to reach levels compatible with the QoS requirements of critical XR applications.

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