

Immersive Media Livestream Distribution of an Opera Performance Over a Private 5G Network

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Abstract—In 2025, HoloEdge delivered a pilot event where an immersive media livestream of opera performance was distributed over a 5G network. A production of *Carmen* by English National Opera was performed in London and streamed to Studio Ulster, Belfast, where the stream was distributed to audience endpoints connected to the private 5G deployment. This included distribution via an LED volume stage and spatial audio loudspeaker system, and distribution via a VR headset with spatial audio headphone playback. This paper provides technical detail on the immersive media livestream system and distribution to audience endpoints over the 5G network at Studio Ulster. This demonstrates a pro-AV and 5-G capable workflow for immersive livestreaming of opera and classical performance. Informal UX is also presented, suggesting a willingness for virtual attendance to such productions. This contributes a novel demonstration of 5G virtual production, which offers support for wireless, high-speed, low-latency, and easy-to-deploy networked virtual production solutions.

Index Terms—Virtual reality, extended reality, wireless networks, 5G, spatial audio

I. INTRODUCTION

In the context of opera and classical music performance, immersive media livestreaming is considered to extend access to performance viewing to remote audiences, and improve engagement with the performing arts [1], [2].

Here livestreaming systems are extended to include immersive Audio-Visual (AV) display technologies, for example Virtual and Extended Reality (VR/XR), immersive screen displays, and spatial audio systems [3]–[6]. Presentation over immersive AV systems can enhance the experience of remote audiences, and improve the sensation of presence in virtual attendance. In the context of immersive media livestreaming of musical performance, 5G networks [7] provide a solution for media distribution [8]. This includes high bandwidth for the transport of immersive media formats, Quality of Service (QoS) optimisation, provision of processing resources at local cells, and 5G-capable wireless device connectivity [9]–[11]. Additionally portable private 5G systems can be deployed to event locations, providing 5G capabilities to venues, and streamlining installation relative to wired network deployments.

This paper presents a case study on immersive media livestreaming and distribution to audiences over a private 5G network. HoloEdge¹ delivered a pilot livestream event featuring the English National Opera (ENO)² production of the opera *Carmen*.

¹www.holoedgedigital.com

²www.eno.org

TABLE I
OVERVIEW OF RECENT STUDIES DESCRIBING IMMERSIVE LIVESTREAM SYSTEMS, HIGHLIGHTING KEY IMMERSIVE DISPLAY TECHNOLOGIES DETAILED AND 5G CAPABILITIES. THE HOLOEDGE IMMERSIVE LIVESTREAM (THIS PAPER) IS ALSO LISTED.

Reference	HMD display	Screen display	Stage display	Spatial audio	Public 5G	Private 5G
[12]	-	-	-	✓	-	-
[13]	-	✓	✓	✓	✓	-
[14]	-	✓	-	✓	-	-
[15]	-	✓	✓	✓	-	-
[16]	✓	✓	✓	-	-	-
[17]	✓	✓	-	✓	-	-
[18]	✓	✓	✓	-	-	-
[19]	✓	✓	✓	✓	-	-
[20]	✓	-	-	✓	✓	-
[21]	-	-	-	✓	-	-
[22], [23]	✓	✓	✓	-	-	-
[8]	-	✓	✓	-	✓	-
This Work	✓	-	✓	✓	-	✓

The opera was performed in London and distributed to audience endpoints located in Studio Ulster³. This includes a venue audience with immersive screen and loudspeaker display, and a Virtual Reality (VR) audience with Head Mounted Displays (HMDs) and headphones. The immersive livestream was distributed to audience endpoints over the CoSTAR Screen Lab⁴ private 5G network. This paper contributes detail on the immersive livestream system, describing the networked Audio–Visual (AV) deployment.

The success of the system deployment is discussed with relevance to the objective of implementing a pro–AV and 5G capable immersive media livestreaming workflow. This contributes a novel description of a 5G–capable immersive livestreaming system which may be used as reference in future deployments. Informal User Experience (UX) evaluation is also presented, detailing audience rating and comment for the experience. This contributes UX data which suggests a willingness for virtual attendance to opera and classical performance via immersive livestreaming. This is discussed with relevance to the wider objective of exploring virtual attendance as a means of accessing opera.

II. RELATED WORK

Practical immersive livestreaming deployment for music performance dates back to at least the late 90s/early 2000s [24]–[26] and continues to be a topic of interest in modern research & development. Several recent papers have highlighted the relevance of immersive livestreaming technologies to industry practice in the performing arts sector, where virtual audiences view commercial performance events via mobile devices, social media platforms, venue displays and installations, HMDs, game environments, and social VR platforms [4]–[6], [19], [22], [23], [27].

Such performance content may be captured for livestream production from live performance, studio performance (including studio installations across core networks), or Network Music Performance (NMP, where musicians perform across Wide Area Network endpoints).

For traditional screen display, the presentation of video via web players, streaming platforms, teleconferencing solutions, and social media is typical. Such streams are accessible to consumer mobile, television, and home computer devices. In practical case study of immersive livestreaming, systems enhance traditional video streaming with spatial audio. This includes non–interactive binaural stereo audio, delivered over headphones with a video stream [14], [15]. This also includes loudspeaker–based spatial audio systems, delivering spatial audio playback over a listening area in screening venues [13], [19]. The content of video streams enhanced with spatial audio includes video capture [13]–[15], and animated content rendered in game environments [19].

Immersive screen displays and XR installations are considered for the presentation of immersive livestreams to live audiences in venues. In practical case study, visual content includes traditional video capture, and also immersive displays such as 360° video mapping to LED volume stage display [16], or the presentation of XR content via stage displays and XR installations [17]–[19]. XR content may include pre–programmed animation, and real–time animation (for example performer avatar animation driven by motion capture systems). Case studies also describe hybrid cases, where live performers are present on stage display, performing alongside an immersive stream presentation of remote performance. This includes the presentation of XR content alongside live performers [18], [19], or spatial audio representation of remote performers with no visual display alongside live on–stage performers [28]. In venue locations, it is typical for spatial audio to be delivered over loudspeakers. Specialist Ambisonic loudspeaker arrays may be used [12].

³www.studioulster.com

⁴www.costarnetwork.co.uk/labs/screen-lab

Consumer surround-sound loudspeaker configurations and venue Public Address (PA) systems may, however, be more commonly available in practice. In this case amplitude-based panning, delay-based panning, and beamforming methods may be more suitable.

HMD presentation of immersive livestreams may take various forms. Practical case study largely considers performance presentation as animation in virtual game environments [19], [23]. Here virtual environments may be hosted via social VR platforms [22], [23], bespoke VR applications [19], or web-based VR solutions [16]–[18]. Such virtual environments may also be presented on traditional screen display. Indeed, immersive livestreaming to virtual audiences in game environments, accessed by users with screen display, is most common in industry practice [22], [23]. To support aural navigation of a virtual environment in virtual attendance, interactive spatial audio is implemented in some systems [17], [19]. Here binaural stereo delivery over headphones is provided, where a range of VR development solutions are available.

The potential for 5G networks to support immersive livestreaming has been highlighted in several recent papers [5], [6], [8]–[11], [27], [29]–[31]. These papers highlight that Software Defined Networking (SDN) and Ultra-Reliable, Low-Latency Communication (URLLC) features of the 5G standard are capable of supporting the fast and reliable streaming of immersive media formats, and supporting optimised QoS for media transport. Additionally the potential for Multi-access Edge Computing (MEC) deployment at cells near performer and audience endpoints provide a solution to immersive media spatial computing and rendering processes. This is considered convenient as it removes the processing requirement from performance, production and audience endpoints, while providing a solution with superior latency to traditional server-based solutions.

Several studies have validated the capabilities of 5G networks to support media distribution across metro areas [32], networked media production [33], and networked immersive media production and distribution [8], [34], [35]. Practical case study has, however, not yet addressed the case of systems for immersive livestreaming of musical performance. Current study in the field of immersive media streaming over 5G networks instead focuses on the case of NMP, rather than audience distribution. In the context of 5G NMP deployment, a range of studies have highlighted that MEC spatial audio processing and 5G distribution for performance content will suffer some signal degradation when operating at latency required for NMP [36]–[39] (i.e., sub-30 ms latency), however stable audio streaming may be achieved at higher latencies which are suitable for audience distribution.

Other work which evaluated audio and video streaming for 5G NMP also concludes that media distribution can be supported at higher latency which is suitable for audience distribution, but in excess of latency required for NMP [40]. Other work has demonstrated the potential for server-based spatial audio rendering solutions for audience distribution of performance content over 5G mobile carrier networks [20].

III. IMMERSIVE LIVESTREAM CASE STUDY

A. Case Study Overview

In 2025, ENO delivered a performance Calixto Bieito's production of Bizet's *Carmen* at the London Coliseum. Associated with this production, HoloEdge delivered an immersive livestream of a dress rehearsal performance (figure 1). This project addressed the development of a 5G-capable immersive livestream workflow, intended to extend access to opera performance. The dress rehearsal was performed in the the London Coliseum. Performance media was captured and streamed to Studio Ulster, Belfast.

At Studio Ulster, the received media stream was distributed for audience presentation over the CoSTAR Screen Lab private 5G network to two audience endpoints (figure 2). A live venue audience in Virtual Production studio 3 (VP3) experienced the immersive livestream presented via an LED volume stage display and loudspeaker array (figure 1). In the CoSTAR Screen Lab research offices, a VR audience experienced the immersive livestream presented as a virtual screening via HMDs.

B. System Deployment

In London, the performance was captured as HD video from a single camera viewpoint with Serial Digital Interface (SDI) output. Orchestral and vocal performance was captured via a range of microphone capture methods. A range of microphone capture methods were used to provide a range of assets for the sound engineer to mix to taste. Decca tree, Office de Radiodiffusion-Télévision Française (ORTF) stereo, and spaced microphone arrays [41] were used to create a frontal stereo mix. A spaced microphone array was used to create a rear stereo mix. First Order Ambisonic (FOA) audio was captured from a central audience location using a Calrec SoundField Mk V microphone. These 8 audio channels were converted to SDI and encoded into the video SDI channels using two Black Magic Mini audio to SDI converters⁵. The SDI signal was input to Haivision video encoder for streaming from London to Studio Ulster, Belfast, where it was received by a corresponding decoder model.

Here, the SDI signal was encoded to H.264 at 1080p resolution for streaming. Transport between sites is performed using the open-source Secure Reliable Transport (SRT) protocol⁶ for low-latency video streaming. The stream is managed from the Haivision Streamhub⁷ control software, which allows configuration of stream parameters, and monitoring of stream performance. Cursory measurement of the stream was taken visually from the Streamhub dashboard, indicating 5.6 Mbps bandwidth consumption, no packet loss, and a Round Trip Time (RTT) latency of < 40 ms between London and Belfast.

⁵<https://www.blackmagicdesign.com/products/miniconverters/techspecs/W-CONM-05>

⁶www.github.com/Haivision/srt

⁷www.haivision.com/products/streamhub-receiver-decoder/



Fig. 1. Immersive livestream presentation to the audience over the VP3 LED volume stage and loudspeaker array.

The values reported in StreamHub for latency⁸ and packet loss⁹ are objective measurements derived from SRT headers, indicating stable values for packet loss and latency during the livestream event. The latency measurement here relates to transport between London and Belfast. Latency across the 5G segment was not measured in-situ, and therefore cannot be reliably reported.

At Studio Ulster, Belfast, the stream is received via the private Stand-Alone (SA) 5G Network. The private 5G network operates on the N77 band (3805–3905 MHz). The 5G network base station, provided by Ericsson, consists of a baseband processor and two radio access units providing radio access to the network. Each radio access unit supports 4x4 Multiple Input and Multiple Output (MIMO) and 256x Quadrature Amplitude Modulation (QAM), and is capable of providing Downlink (DL) in excess of 1 Gbps and Uplink (UL) in excess of 200 Mbps (though DL in excess of 700 Mbps and UL in excess of 100 Mbps are more typically experienced in practice).. The two radio access units are connected to the baseband processor via a 5 Gbps fibre connection, and are installed in VP3 and in the CoSTAR Screen Lab research offices. The network is synchronised from Global Navigation Satellite System (GNSS) signal using an Ericsson receiver unit and active antenna. Internet connection is provided by a gateway to the British Telecom (BT) backhaul.

The immersive livestream was received at Studio Ulster and distributed via the 5G network. In VP3 a 5G router provides wireless connection to the private 5G network. The 5G router allows access to the 5G network for hardware which is not 5G-native (i.e., cannot connect directly via radio access), and requires bridging to the 5G network via a wireless connection to the router. A Haivision decoder with wired connection to the router receives the H.264 stream and outputs via SDI. Two Black Magic Mini Audio to SDI converters¹⁰ were used to de-embed audio from the SDI signal. The FOA and stereo signals were input to a Yamaha DM3 mixing console¹¹, providing level control and Analogue-to-Digital (AD) conversion. A point-to-point Dante connection was used to transport these channels to a d&b Audiotechnik Soundscape system¹² for loudspeaker presentation to the audience.

The system consists of a laptop, DS100 DSP hardware¹³ and bespoke 16 channel surround-sound loudspeaker array provided by d&b Audiotechnik. The loudspeaker array includes a subwoofer and 15 satellite speakers. The laptop hosts the Soundscape application, and a bespoke upmixing system used to upmix the FOA signal to 7th Order Ambisonic (7OA) signal.

¹⁰<https://www.blackmagicdesign.com/products/miniconverters/techspecs/W-CONM-22>

¹¹<https://uk.yamaha.com/en/business/audio/products/mixers/dm3/>

¹²www.dbaudio.com/global/en/solutions/integration-and-interoperability/soundscape/

¹³www.dbaudio.com/global/en/products/processing-and-matrix/ds100/

⁸<https://doc.haivision.com/SRT/1.5.4/Haivision/latency>

⁹<https://doc.haivision.com/SRT/1.5.3/Haivision/packet-loss-rate>

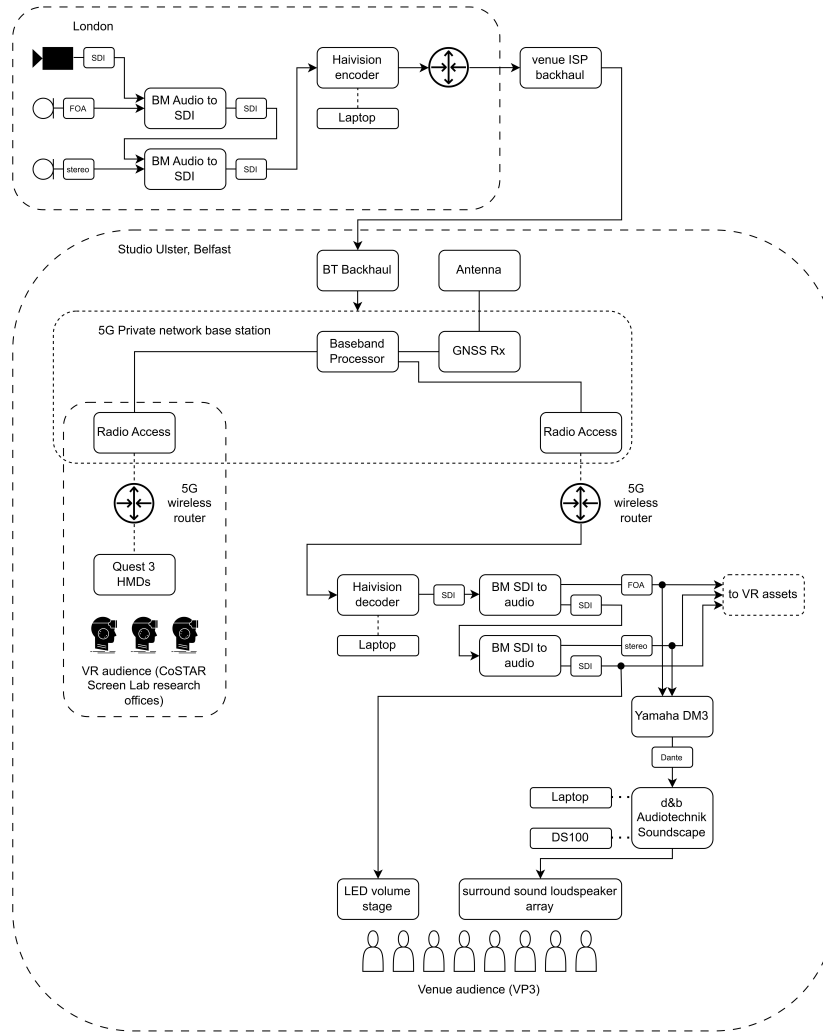


Fig. 2. Overview of the immersive livestream system deployment.

Upmixing the FOA signal increases the spatial resolution of the Ambisonic signal, and was performed using commercially available plugins. Loudspeaker decoding of the 7OA signal is performed using commercially available plugins to provide 15 virtual loudspeaker signals. These virtual loudspeaker signals, as well as the front and rear stereo channels are routed to the DS100 via Dante, and are placed as virtual source objects for spatial audio playback over the physical loudspeaker array using DS100 control software. The SDI video signal output, describing a single viewpoint, is input to the LED volume stage (Brompton Technology SX40 processor¹⁴ and Roe RB2.2 LED panels¹⁵) display for audience presentation.

In London, the SDI video feed, and FOA and stereo audio signals, were also routed as assets for the VR immersive livestream presentation. Similar to loudspeaker rendering, virtual loudspeaker feeds were placed as virtual sources and rendered binaurally to provide a spatial audio stereo headphone mix. A browser-based video stream with the headphone mix was prepared for streaming to the VR audience in Belfast. At the CoSTAR Screen Lab research offices in Belfast the VR audience was delivered a virtual screening experience, where a bespoke Unity application developed by HoloEdge presents the browser-based stream. Here, the single viewpoint video capture is presented on a virtual screen which is placed in the virtual screening environment.

¹⁴www.bromptontech.com/product/sx40/

¹⁵www.roevisual.com/nl-en/ruby

The VR presentation is delivered using Meta Quest 3¹⁶ HMDs. The HMDs are connected to the private 5G network via a 5G router which provides a Wireless Access Point (WAP) for the HMDs, and provides internet access required by the bespoke Unity application. Figure 2 shows architecture of immersive livestreaming system with key components and locations. All asset capture used in livestreaming was captured for post production in London. In addition to immersive livestream asset capture, 360° video capture was also performed for use in post production. This was performed using an Insta360 Titan¹⁷ 360° camera. This 360° camera feed was not used in the livestream, however, where only single viewpoint video assets were used.

C. User Experience

Informal User Experience (UX) evaluation was conducted following the immersive livestream event. Participants ($N = 16$) provided demographic information and feedback on the experience via an exit questionnaire delivered via Google Forms. 9 participants had never attended an ENO event previously, and 5 of these participants had never attended an opera event. 9 participants were female, 4 participants were male and 3 participants did not report gender. For participant age 4 participants were 16–24, 1 was 25–34, 2 were 35–44, 4 were 45–54, 2 were 55–64, and 1 was 65–74. 2 participants did not report age. Participant prior experience with VR or spatial audio was not recorded.

The experience was rated via a single questionnaire item: ‘How likely would you be to recommend an ENO event to your family/friends’ (figure 3). Participants provided response using a rating scale describing degree of likelihood (‘I definitely wouldn’t’, ‘I probably wouldn’t’, ‘I’m not sure’, ‘I probably would’, ‘I definitely would’). Participants also provided comment on the immersive livestream experience in response to comment prompts (table II and table III). Rating indicated that participants almost unanimously agreed that they would recommend immersive livestream events, with the exception of a single outlier (figure 3). Notably, participants who provided UX response had either experienced just the venue presentation, or both venue and VR presentation. No participant had experienced only the VR presentation. As such, direct comparison of rating between venue presentation and VR presentation is not possible from UX response.

Participant comment on the immersive livestream experience (table II and table III) was also overwhelmingly positive. Several comments suggest a positive experience with respect to sensation of presence. One participant noted that they enjoyed ‘feeling part of the production’ and another responded that they ‘enjoyed feeling that you were part of a real audience.’ Another participant commented that the venue presentation was ‘almost as good as being in the theatre.’ Positive comment was also made regarding the experience of spatial audio.

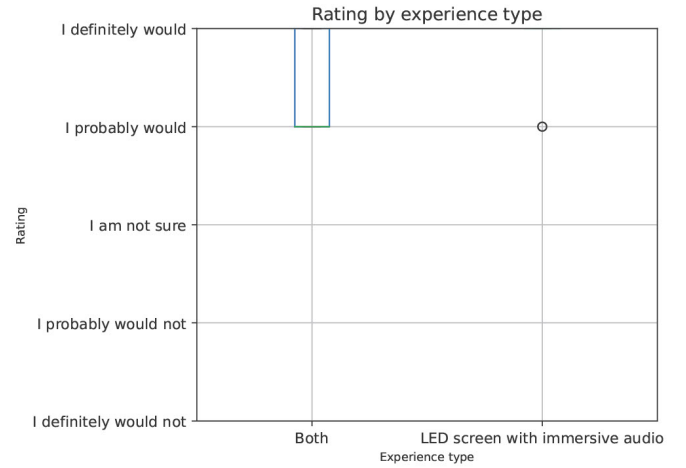


Fig. 3. Results for rating of the immersive livestream experience. It is indicated whether participants experienced only the venue presentation ($N = 5$), or both the venue and VR presentation ($N = 11$). No participant only experienced the VR presentation.

One participant commented that the venue presentation ‘sounds fantastic’, and another participant who experience only venue presentation noted that they ‘enjoyed the immersive audio acoustics.’ One participant who experienced only venue presentation noted that though ‘audio was good’, the single viewpoint video display was ‘rather basic.’ Participants also commented suggesting a desire for virtual attendance of opera via immersive livestream events. When asked what would increase participants likelihood to attend ENO events, one participant responded ‘A virtual showing like this would increase my likelihood of attending another ENO event’. Another participant indicated that streaming to cinema venues would improve likelihood of attendance (‘Streaming to cinema’).

IV. DISCUSSION

The first objective of this case study event was to develop a pro-AV and 5G-capable immersive livestreaming system. The system detailed captures, streams, and displays video and spatial audio content over both venue and VR audience endpoints. Informal note of stream metrics suggests stable and low-latency streaming. Additionally, informal UX suggests a positive audience experience. In this regard the presented system successfully achieves this first objective, and provides tutorial resource for future events.

The second objective of this case study event was to explore immersive livestreaming to support access to opera and classical performance through virtual attendance. Several participants who had not attended opera or ENO events before indicated a willingness to recommend virtual attendance based on the immersive livestream experience. Additionally, participant comment suggests a positive audience experience and a willingness to access opera by virtual attendance to immersive livestream events.

¹⁶www.meta.com/gb/quest/quest-3/

¹⁷www.insta360.com/product/insta360-titan

TABLE II

PARTICIPANT COMMENTS IN RESPONSE TO THE QUESTION: ‘PLEASE LET US KNOW WHAT YOU ENJOYED MOST ABOUT THE EVENT.’ EXPERIENCE TYPE IDENTIFIES WHETHER THE PARTICIPANT MAKING THE COMMENT EXPERIENCED ONLY THE VENUE PRESENTATION, OR BOTH THE VENUE PRESENTATION AND VR PRESENTATION.

Comment	Experience Type
<i>Enjoyed the opportunity to experience both aspects. Feels so close to what was happening.</i>	Both
<i>I enjoyed the VR headsets most.</i>	Both
<i>I enjoyed the immersive experience (venue presentation) most.</i>	Both
<i>I enjoyed experiencing the VR headset - feeling part of the production.</i>	Both
<i>It was almost as good as being in the theatre.</i>	Venue presentation
<i>I enjoyed the difference between the VR and immersive experiences (venue presentation). Very enjoyable and informative.</i>	Both
<i>I enjoyed feeling that you were part of the real audience.</i>	Venue presentation
<i>Sounds fantastic.</i>	Venue presentation
<i>The audio was good, the video rather basic.</i>	Venue presentation
<i>I really enjoyed experience of the opera via the LED screen.</i>	Venue presentation
<i>It gave a very immersive aspect to the stream.</i>	Venue presentation
<i>I enjoyed the immersive audio acoustic and would have loved to experience that in a headset to see if and how that further deepened the immersion of the audio.</i>	Venue presentation

TABLE III

PARTICIPANT COMMENTS IN RESPONSE TO THE QUESTION: ‘IS THERE ANYTHING THAT WOULD INCREASE YOUR LIKELIHOOD OF ATTENDING ANOTHER ENGLISH NATIONAL OPERA EVENT.’ EXPERIENCE TYPE IDENTIFIES WHETHER THE PARTICIPANT MAKING THE COMMENT EXPERIENCED ONLY THE VENUE PRESENTATION, OR BOTH THE VENUE PRESENTATION AND VR PRESENTATION.

Comment	Experience Type
<i>Yes more free opera.</i>	Both
<i>This is a fascinating project, would love to see it develop further.</i>	Both
<i>A virtual showing like this would increase my likelihood of attending another ENO event.</i>	Venue presentation
<i>Streaming to cinema.</i>	Venue presentation
<i>Not really, if I was in London and there was a title I liked, or an artist I wanted to see I would consider attending..</i>	Venue presentation

It can also be noted that positive rating and willingness to recommend opera events was expressed by participants who had not previously attended opera events. This suggests that immersive livestreaming and virtual attendance can indeed extend the reach of opera performance to those who would not otherwise attend opera events.

V. CONCLUSION AND FURTHER WORK

This paper has provided technical detail on a 5G-capable and pro-AV immersive livestreaming system, distributing the stream to VR and venue audience endpoints over a private 5G network. System measurement contributes a demonstration of 5G network support for the transport of immersive livestream assets and for audience distribution in immersive livestream presentation. Detail on implementation contributes a technical tutorial on how to deploy immersive livestream systems over 5G networks.

Informal UX evaluation suggests that, based on the immersive livestream experience, participants would recommend accessing opera through virtual attendance. Participant comment and willingness to recommend may indicate a positive audience experience, however further UX evaluation will be required to formally model the audience experience. This participant feedback contributes an indication that immersive media livestreaming is indeed a suitable approach to facilitating virtual attendance to opera and classical performance events.

Notably the presented system considers video and spatial audio assets. Further work may consider motion capture and animation-based systems, volumetric capture and display systems [35], [42], and ‘holographic’ display systems [43]. Systems which allow remote production and operation [8] may also be integrated into workflows. More complex 5G networks, for example metro area distribution systems may also be the topic of further immersive livestream case study. Other livestream contexts, such as streaming of NMP content, should be considered in the context of 5G networking. System Key Performance Indicator (KPI) measurement and UX can be identified as informal in this case study, and considering end-end performance rather than measuring the 5G network segment discretely. Further work may include more robust KPI measurement and UX evaluation. KPI measurement here for networking should consider the performance of the 5G network segment discretely. Further UX may include perceptual and objective evaluation of spatial audio rendering across presentation contexts.

ACKNOWLEDGMENTS

This research is supported by the CoSTAR Screen Lab (AH/Y001044/1) and Studio Ulster in collaboration with HoloEdge as part of the CoSTAR Prototypes and Pilots programme. Thanks is extended to HoloEdge, Toby Young from Guildhall School of Music & Drama, English National Opera, and Stunt Double Music for their collaboration on this project.

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