DCMS 5G TESTBEDS AND TRIALS PROGRAMME
5G CREATE GRANT FUNDING COMPETITION

PROJECT 5G FESTIVAL

Milestone Evidence (MS7b)

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1. Introduction & Showcase Videos

The purpose of this document is to provide evidence for MS7b Milestones as agreed in the 5GF milestone and the GFA.

Table 1: Milestone 7b

Milestone	Milestone description	Components (Deliverables)
MS7b	Beta prototype completed	• **D-7b.1**: Beta Prototype Complete UC1
		• **D-7b.2**: Beta Prototype Complete UC2
		• **D-7b.3**: Beta Prototype Complete UC3

Showcase Video Link

Warner Music Group - 5G Festival Documentary

2. 5GF Platform Beta Prototype

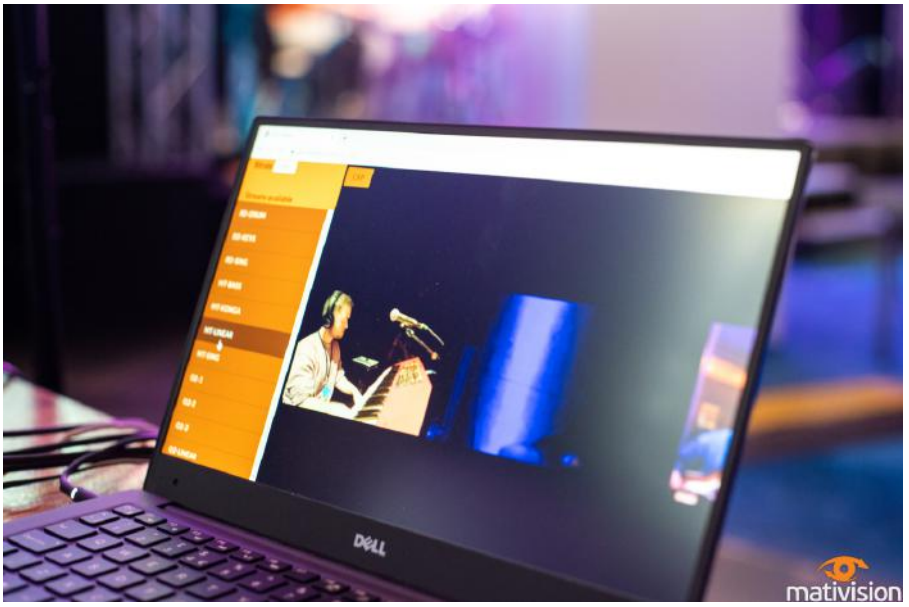
2.1. Common Service Platform (CSP) status

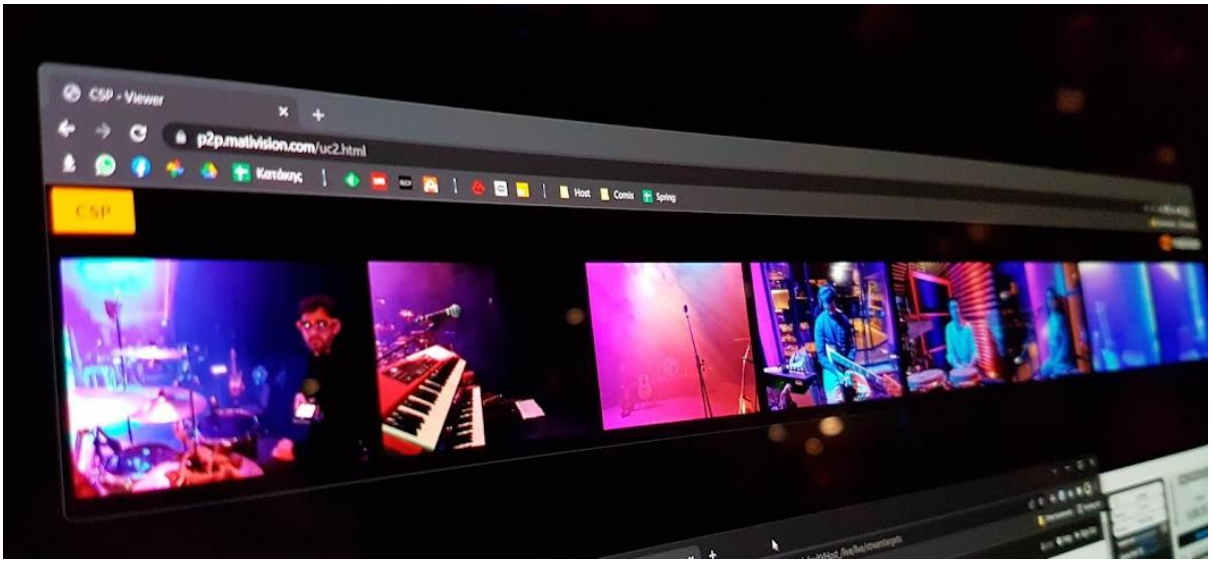
Our main objective for the 5GF Beta Prototype was to ensure that it was effective and intuitive to use for the artists performing as part of the 5G Festival. The Common Service Platform (CSP) was used to transport the live video feed from one venue to the other. In preparation for the final showcase event, the CSP was updated with the features outlined below to provide a better experience for both the artists and professionals participating. The new CSP version provided a revamped User Interface (UI) and User Experience (UX) based on experiences and feedback gained from previous trials.

The new UI provided a foldable control panel that allowed more screen real estate, or space on the screen, and more resolution for each of the incoming CSP streams. The UI also provided more intuitive controls on mobile devices and the AR Nreal headset that were used by the performers. This new UI allowed both hardware plugins UC1 and UC3 to be used by the show producers and audience to create fullscreen experiences without the need to crop or hide any CSP controls present in the browser window.

Also implemented in the updated version of the CSP was an “auto-reconnect” feature. This functionality reconnected streams that dropped due to connectivity issues automatically, for example, WiFi resets, 5G drops etc. This allowed devices to run standalone without the need for user or crew interaction, even in instances where other devices were trying to re-establish a connection to the CSP. This feature was present in both the receiving application and the broadcasting application. On the broadcasting application, if the device experienced any connectivity issues, the application would try to reconnect when re-established on the CSP;the feature was triggered on the reconnect event fired by the CSP. This feature helped all use cases to provide an easy workflow with minimal user interaction once the device was set to broadcast, receive a stream or both.

Figure 1: CSP Interfaces & Bitrate Outputs





The updated CSP also provided controls for choosing a bitrate, or the number of bits processed in a given timeframe, of the incoming stream for monitoring and debugging purposes. This was set on the receiving application UI. The receiving application, when establishing a connection with a remote peer, would provide the target bitrate to the broadcasting application and the minimum bitrate to use. A default target bitrate was set for both UC1 and UC3, but each user on the CSP could select a bitrate depending on their requirements. This receiving application would then notify the broadcaster of the target bitrate the user/device wants to achieve and would set the minimum bitrate to half of that of the target bitrate. The connection started out at the minimum bitrate and would switch to a higher bitrate and resolution depending on network conditions. This approach allowed each device to achieve a high bitrate while also providing some room for adjusting the bitrate based on network conditions. A constant, non changing bitrate can also be set to the

minimum, and target bitrates are set to the same value. But during testing this proved unstable as it didn't allow any room for changing network conditions.

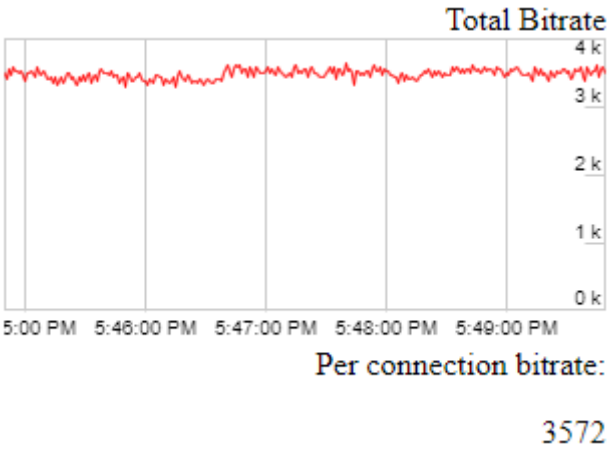
The bitrate selection allowed devices with smaller screens such as UC1 to conserve bandwidth by selecting a smaller bitrate (2-4Mbps) going over the network while allowing UC3 to select larger bitrates (4-10Mbps) and achieve better quality as they are targeting broadcast quality and equipment.

Figure 2: Bitrate selection

The bitrate selection was stored to the device storage to allow users quicker reconnection time if a browser window was refreshed.

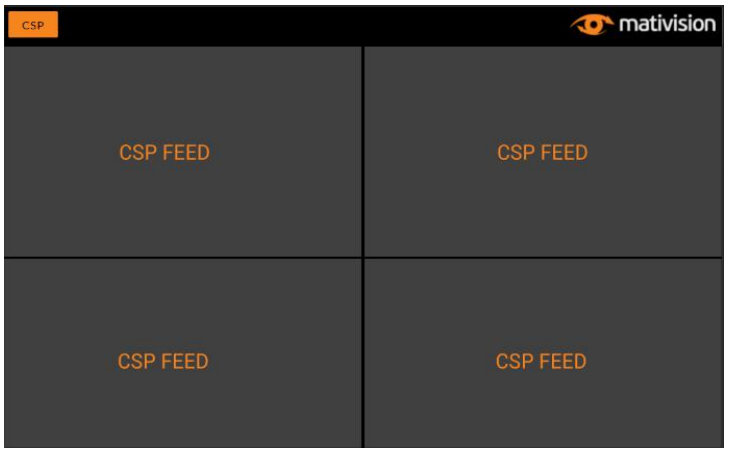
On the broadcasting application, the updated CSP provided a graph showing outgoing bitrate statistics. This graph illustrated the total bitrate going out of each device. The CSP broadcaster analysed the statistics of each outgoing connection and calculated the bandwidth. Each bitrate was added to a table (under the graph) for easy reference, and the combined total of all connections was summed up to the total outgoing bitrate. The total was then plotted to a convenient graph showing outgoing bitrate over time. The graph was set to update every 1000 milliseconds.

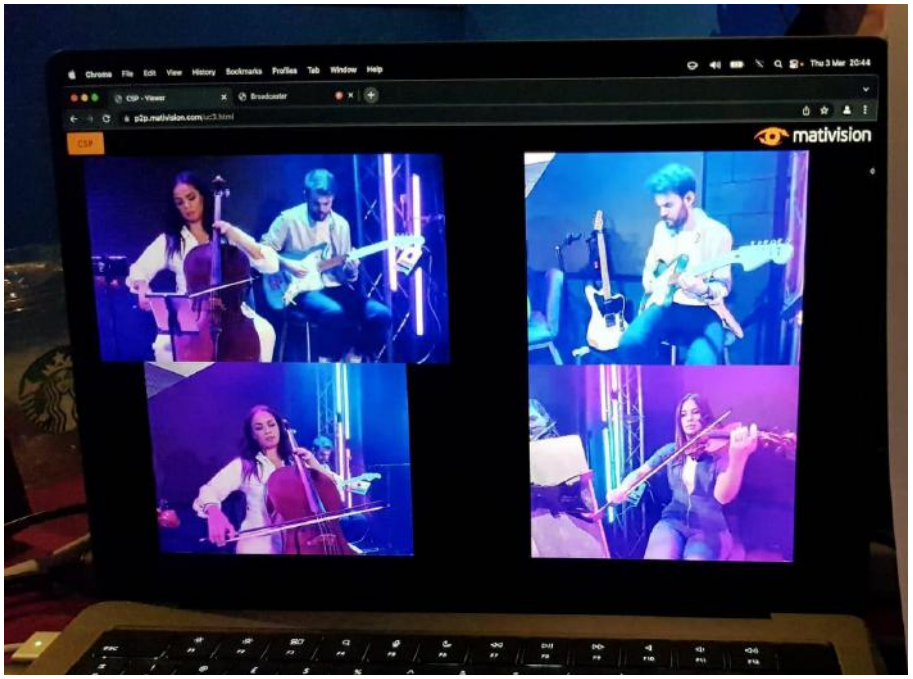
Figure 3: Total Bitrate over time



Multiple type of layouts(arrangement of monitoring outputs) on the receiving application were set-up for the showcase event. These layouts were built based on feedback from the January trial and feedback from UC3 receivers. For the projections (of incoming videos), a four window display was set up. Each CSP incoming stream would take up ¼ of the allocated screen size providing enough resolution to feed the projections up to a Full HD resolution when connected to a high enough resolution display.

Figure 4: Example of layouts on the receiving application.





In addition to the new layout, the auto-reconnect feature took the layout of the screens into account and reconnected the stream to the allocated quadrant of the screen. This feature allowed the rest of the streams to continue uninterrupted while the dropped stream reconnected, as well as enabling a fixed layout to be fed into the projection software.

To allow for the ingest of the CSP feed into the video editing software of UC3, a single screen layout was implemented. This layout also provided controls for the feed to be set fullscreen hiding all other controls, thus maximising the resolution of the incoming feed. For

example, a 1080p feed would display at full resolution on a 1080p display. The auto-reconnect functionality took into account the layout of the single feed and reconnected the feed to the same video element, allowing for reconnection without any interaction by the user, even when in fullscreen mode and controls were hidden.

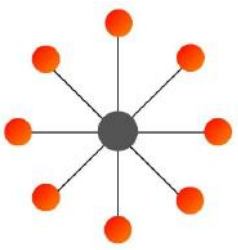
Figure 5: Example of 1080p feed display at full resolution

2.2. CSP Project Summary

The CSP set out to achieve low latency transmission of video over a network via Peer to Peer (P2P) to seamlessly connect artists and video professionals. The goal was to achieve as low latency as possible with existing hardware and provide an intuitive user experience. During the development of the CSP, multiple iterations and methodologies were tested and trialled.

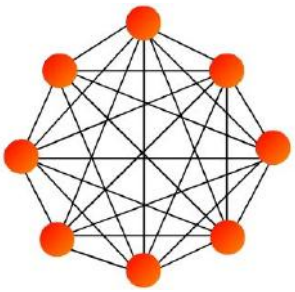
The first iteration used a virtual machine (VM) to relay footage between devices. The star network topology, where every host connects to a central hub (illustrated below), made it easy to transfer multiple videos over a single connection, but failed in terms of latency. This was because the resulting latency was disruptive to artist collaboration. The relaying of footage added an extra hop and extra processing that resulted in about 500ms latency between an event being recorded and displayed on the receiving device.

Figure 6: Star network topology



The v2.0 of the CSP used direct P2P connections between devices in a mesh network topology, with no central hub (illustrated below). This topology made it so that each connection was direct from the receiving device to the broadcasting device. The resulting end-to-end latency of the v2.0 CSP was 30-60ms. The mobile devices had a camera capture latency of 100ms capturing and displaying a frame on screen. The resulting end to end latency CSP was 130-160ms, depending on the distance between devices. The downside to this approach was that each device had to handle multiple connections.

Figure 7: P2P Mesh network



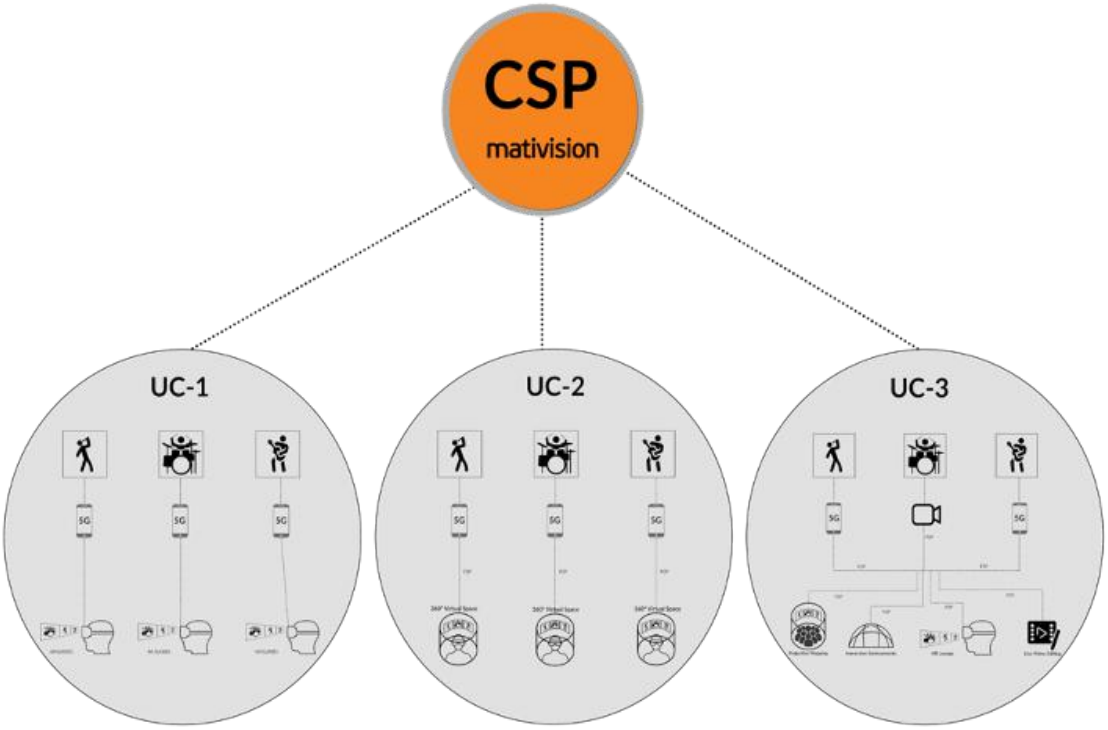
For example, for the showcase event, 12 devices were broadcasting on the network. These devices were being received in/by multiple locations, up to 15 receiving devices (UC1 devices, UC1 Nreal headsets, UC2, UC3 Projections, UC3 linear video, multiple monitoring devices). This meant that each device could be encoding and sending up to 15 streams at the same time in some scenarios, with about 100 streams being transferred over the network at any given time.

The resulting latency of the encoding - transfer - decoding latency of 60ms is close to real time and within the latency artists can easily work with.

The main lesson learnt from the project, in regards to hardware latency, is that video recording/capture devices such as mobile phones, wired USB cameras, SDI camera, HDMI cameras, HDMI capture cards all have different latencies.

The fastest device tested was the mobile phone on device capture, which had a a latency of 100ms. The most latent device tested was the depth sensing camera with 250+ms of latency, depending on lighting conditions.

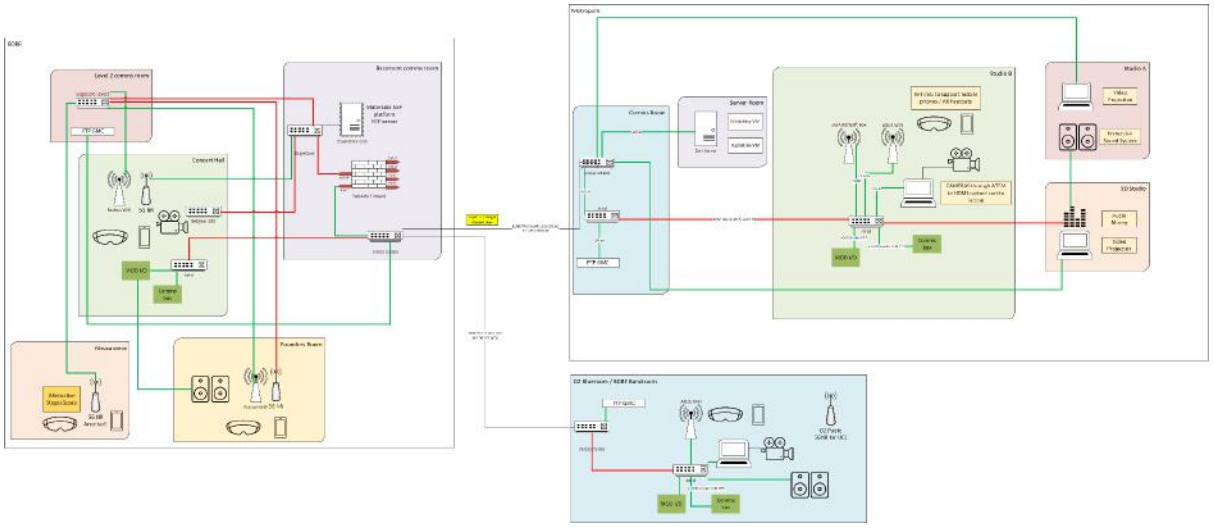
Figure 8: CSP Architecture



3. Network

The 5G network infrastructure deployed to support the 5G Festival application consisted of three sites, interconnected through dedicated leased lines. The network and capabilities of each site were upgraded to offer a more stable wireless network. More specifically, a 5G Standalone Access (SA) was installed in Brighton Dome and Brighton Festival (BDBF), as well as an 5GNR pop-up network in Metropolis and a new wireless access point in the O2 Blueroom.

Figure 9: 5G Infrastructure (Full Scale Version)



3.1. 5G Testbed Infrastructure status

3.1.1. Upgrades to 5G SA

The 5G testbed in Brighton Dome has been upgraded as planned to support 5G Stand Alone, with new Radio Access Network (RAN). This was installed in the Concert Hall using Airspan AirVelocity 2700, an OpenRAN compliant system supporting O-RAN split 7.2x deployments. The Airspan OpenRANGE06 AirVelocity 2700 (RU) provides 5G-New Radio (NR) sub-6 GHz indoor coverage. The Open Ran solution is fully containerised and deployed in two Dell R740 servers in BDBF. Network diagram is shown in Figure 4. We have used 100MHz bandwidth in 3.6 GHz. The 5G Core (5GC) used is the Druid core hosted in Digital Catapult Future Network Lab (FNL) site in London and connected over IPSec tunnel to the network in BDBF. This is one of the reasons why the performance of the new system is not optimal, with downlink speeds around 300MBps and upload 50Mbps. This deployment includes two 5G SA cells. Full configuration of cell-1 is shown in Table 2 and Figure 5.

Figure 10: 5G SA network diagram (CU, DU, ACP, K8S master and 5G SA core)

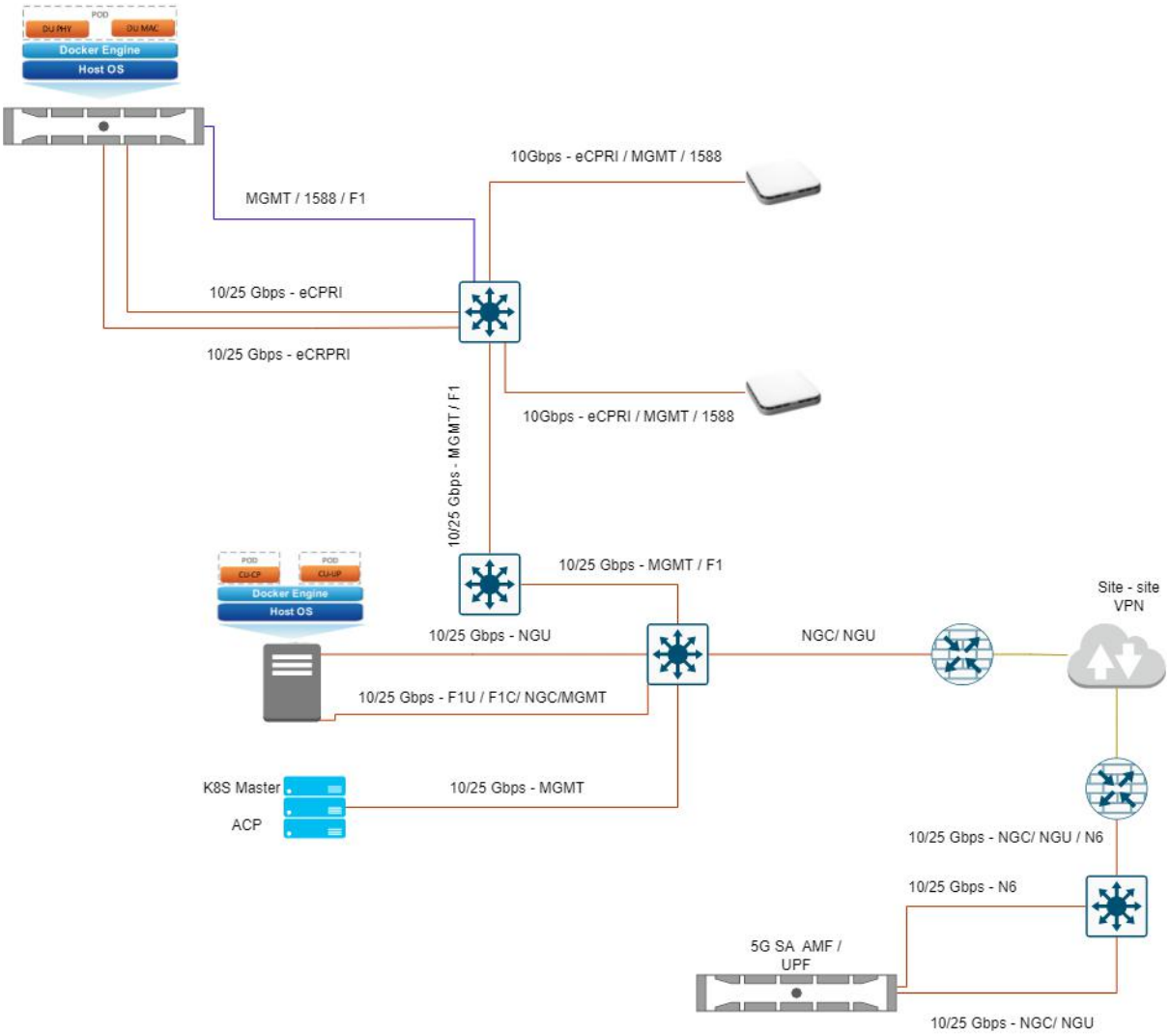
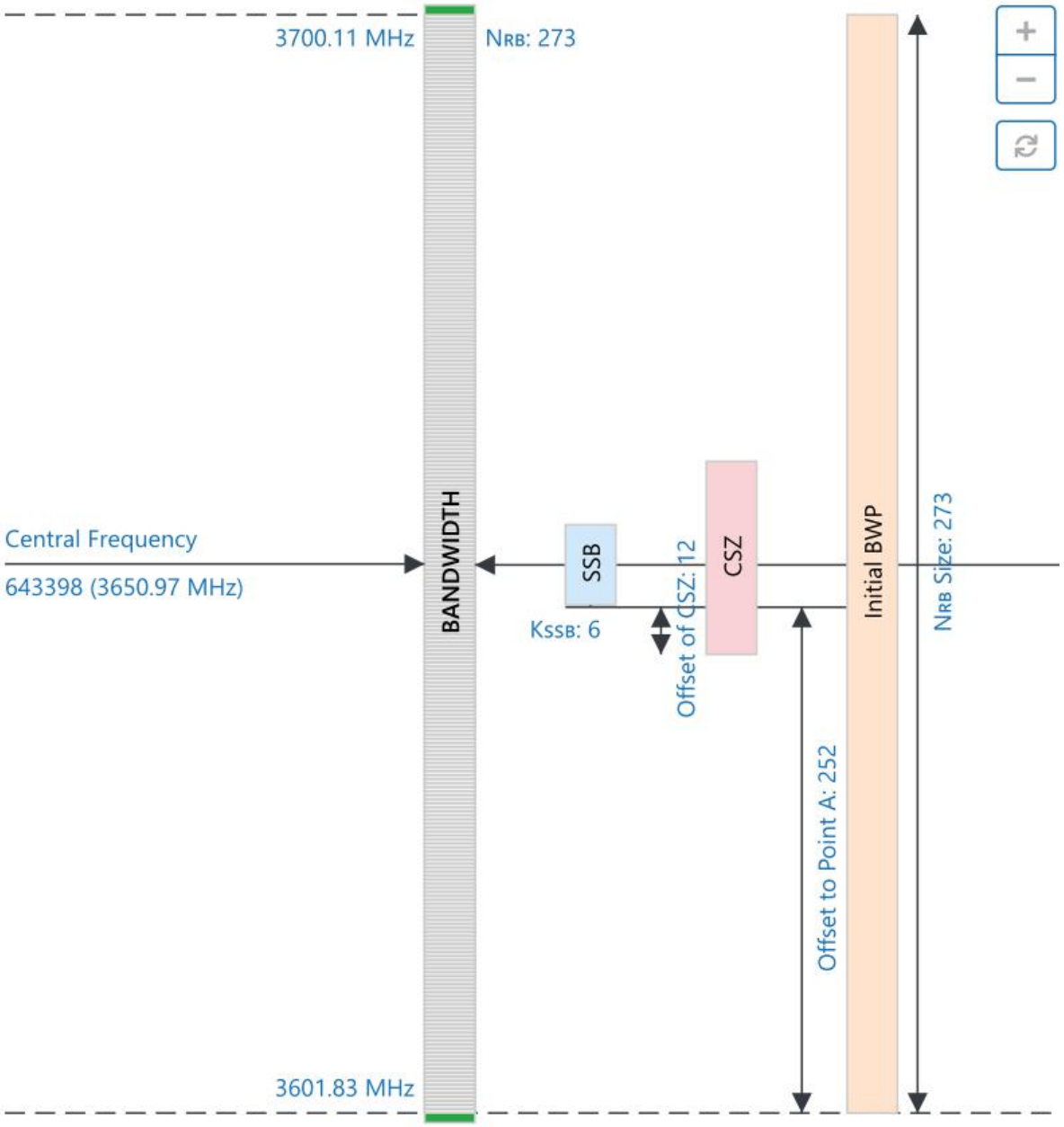


Table 2: DU Cell 1 configuration

Category	Parameter	Value
DU Cell Properties	REST ID	1
DU Cell Properties	Cell Number	1
DU Cell Properties	Enable Cell	TRUE
DU Cell Properties	Local Cell ID	1
DU Cell Properties	Cell Identity	000000011

DU Cell Properties	NR-PCI	1
DU Cell Properties	NR-TAC	1
DU Cell Properties	Band	n78
DU Cell Properties	Duplex Mode	TDD
DU Cell Properties	PDCCH Subcarrier Spacing (kHz)	30
DU Cell Properties	SSB Subcarrier Spacing (kHz)	30
DU Cell Properties	Enable CBRS	FALSE
DU Cell Properties	Bandwidth (MHz)	100
DU Cell Properties	NR-ARFCN	
DU Cell Properties	NR-ARFCN	643398 (3650.97 MHz)
DU Cell Properties	Bandwidth Part Size (MHz)	100
DU Cell Properties	GSCN	7951 (3650.88 MHz)
DU Cell Properties	SSB Periodicity (ms)	20
DU Cell Properties	SSB Offset (ms)	0
DU Cell Properties	SSB Duration (ms)	4
DU Cell Properties	PLMN 1	test (MCC 001, MNC 01)
DU Cell Properties	S-NSSAI 1	eMBB (1, 000000)

Figure 11: 5G SA cell-1 bandwidth configuration



3.1.2. Metropolis 5G Network

Ofcom granted us a trial and innovation licence for 5G at Metropolis Studios, which enabled us to install a 5G node in Studio B. This consisted of our Amarisoft Box, used previously in Brighton Dome connected back to the CISCO switch. Some performance testing on that network matches similar observations, as when we used this at the venues in Brighton, illustrating that latency is slightly greater on the 5G network than the WiFi. In terms of throughput, we observed similar performance for User Data Protocol (USD) traffic (requesting 10 parallel streams of 5MBps) but there was more lost packets and higher jitter

in 5G. This was expected, due to the fact that the system installed is not carrier grade, and consists of very low power Software Defined Radios and in some cases it was unreliable (power fluctuations cause disconnections).

Table 3 - Round Trip latency from Metropolis network to other venues

From Metropolis UE to	WiFi (rtt min/avg/max/mdev)	5G (rtt min/avg/max/mdev)
DNS Server	8/12/17/2.9 ms	22/35/80/11.8 ms
P2P Server	7/11/19/3.1 ms	25/54/855/114.6 ms
Brighton Dome UE (5G)	17/1001/2804/732.3 ms	20/592/2774/669.7 ms
O2 UE	15/25/82/12 ms	45/61/111/11.3 ms

Table 4 - Throughput test from Metropolis to Brighton

From Metropolis UE to BD UE	Bandwidth Jitter Lost/Total Datagrams
WiFi	49.9 Mbits/sec 1.301 ms 0/38080 (0%)
5G	49.9 Mbits/sec 38.217 ms 16999/37690 (45%)

3.1.3. Upgrades for stability of WiFi infrastructure

During previous trials, the wireless network in Metropolis and O2 Blueroom was not reliable enough for UC1. This was because the WiFi APs (Ruckus) used required access to the cloud controller running in the Brighton testbed, but connectivity was not feasible without major changes to the infrastructure. The solution was achieved by replacing the Ruckus APs with off-the-shelf WiFi6 capable APs (ASUS), allowing us to upgrade the stability of the WiFi infrastructure.

3.1.4. Network Utilisation

Using monitoring tools installed on the servers, we captured the traffic and resource utilisation during the last week (Showcase week). In particular, we analysed the performance of the virtualised servers hosting 5GF CSP. The first was the Peer-to-Peer (P2P) server that is used to set up the P2P links between the artists' phones and all internal users that connect to stream, (UC3). The second was theCommon server, which was used to deliver the content to the global Content Delivery Network (CDN) and directly to the Funders Room and other in-venue players. Finally, we measured the backhaul traffic between the sites that was going through the three CISCO switches.

- Backhaul traffic

The setup with two leased lines connecting Brighton with Metropolis and The O2 has effectively created a hub-spoke infrastructure, and the monitoring the hub (Brighton) gave us a lot of valuable information for monitoring and debugging of network purposes.

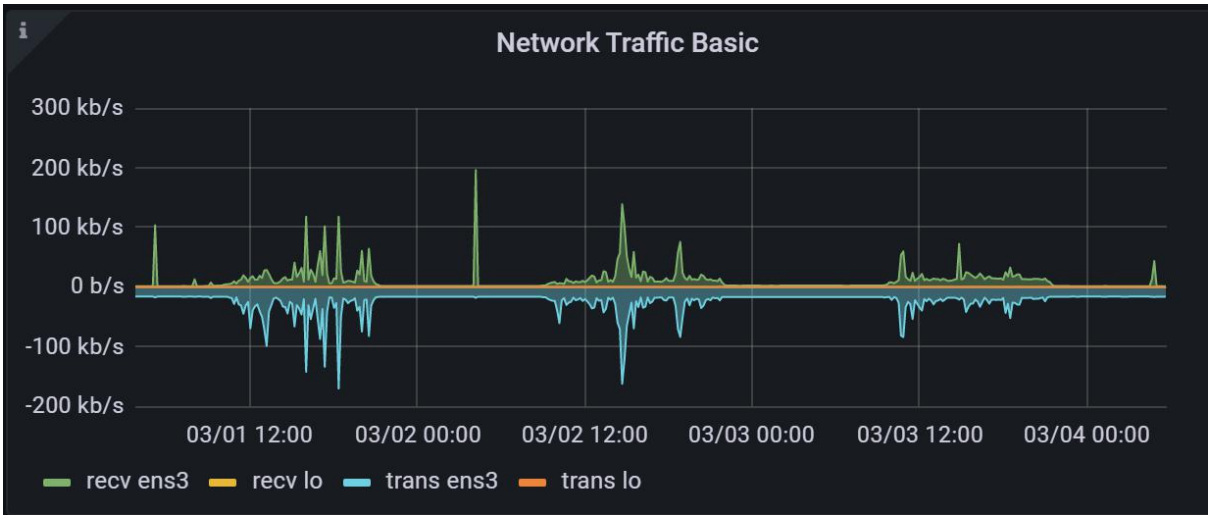
Table 5 - Brighton CISCO monitoring data during live performance

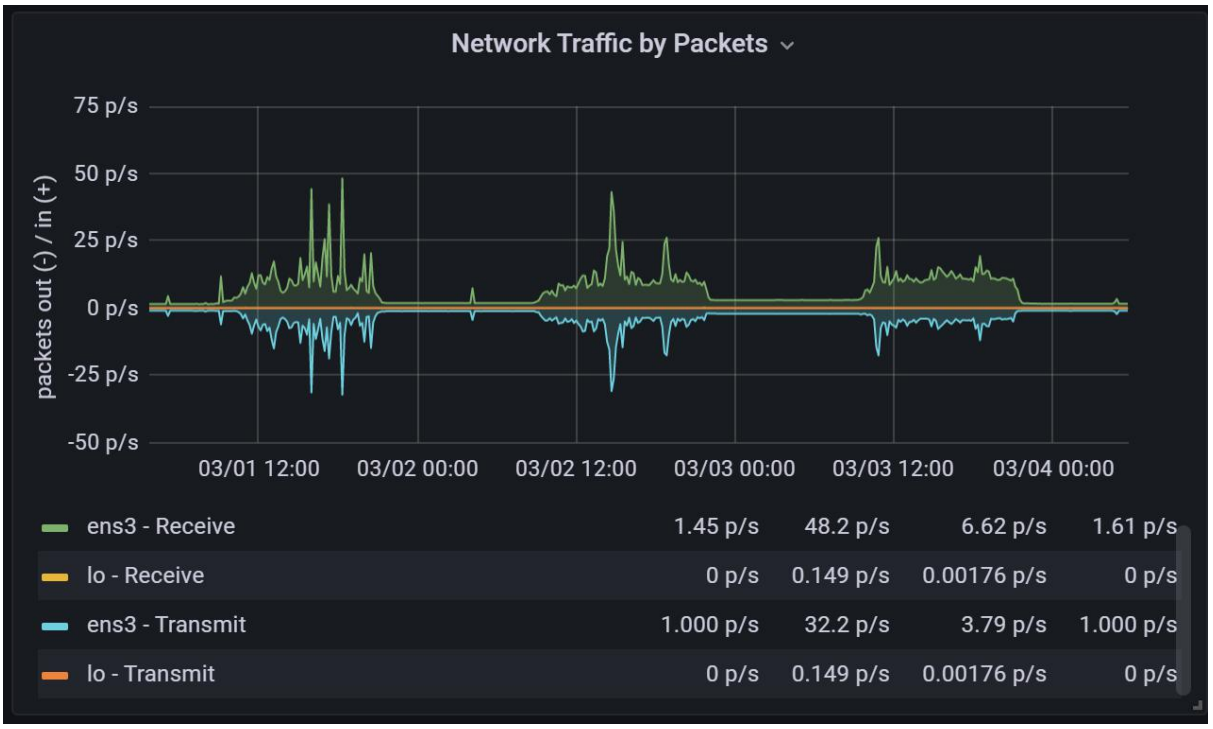
	Incoming	Outgoing
Brighton CSP / Internet	35 Mbps	17 Mbps
Metropolis Link	93 Mbps	168 Mbps
O2 Link	75 Mbps	134 Mbps

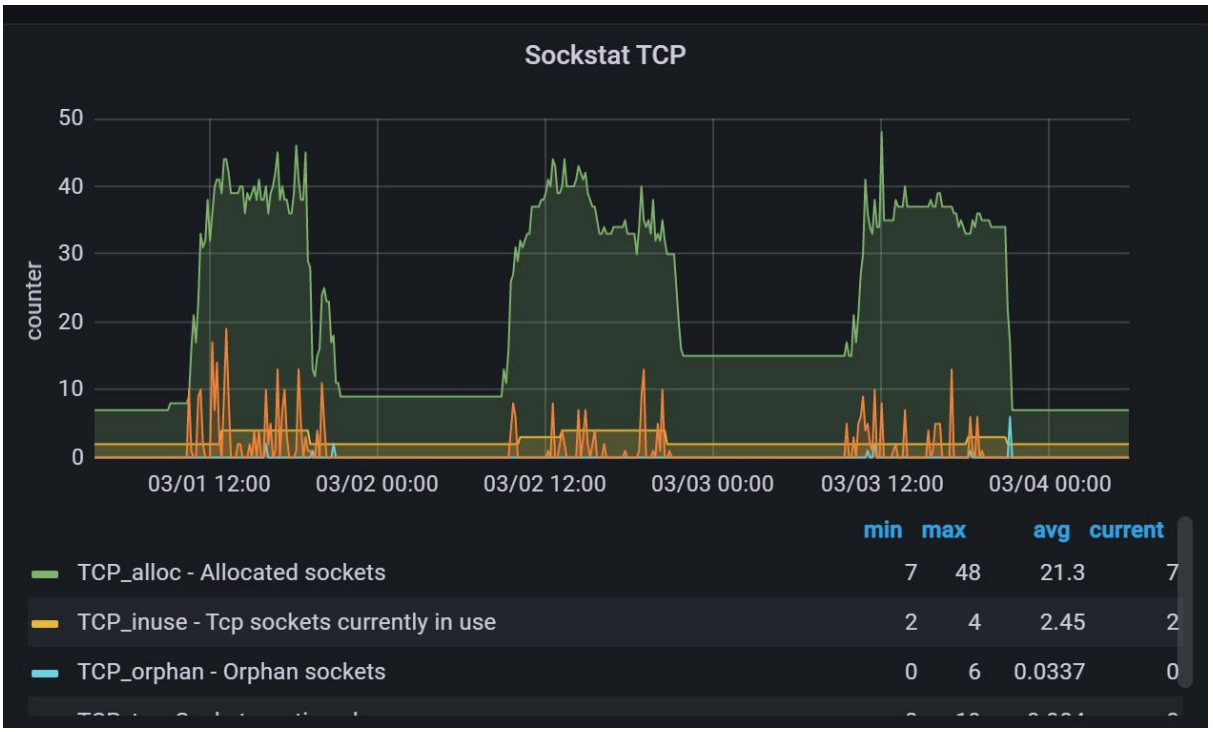
- P2P Server traffic

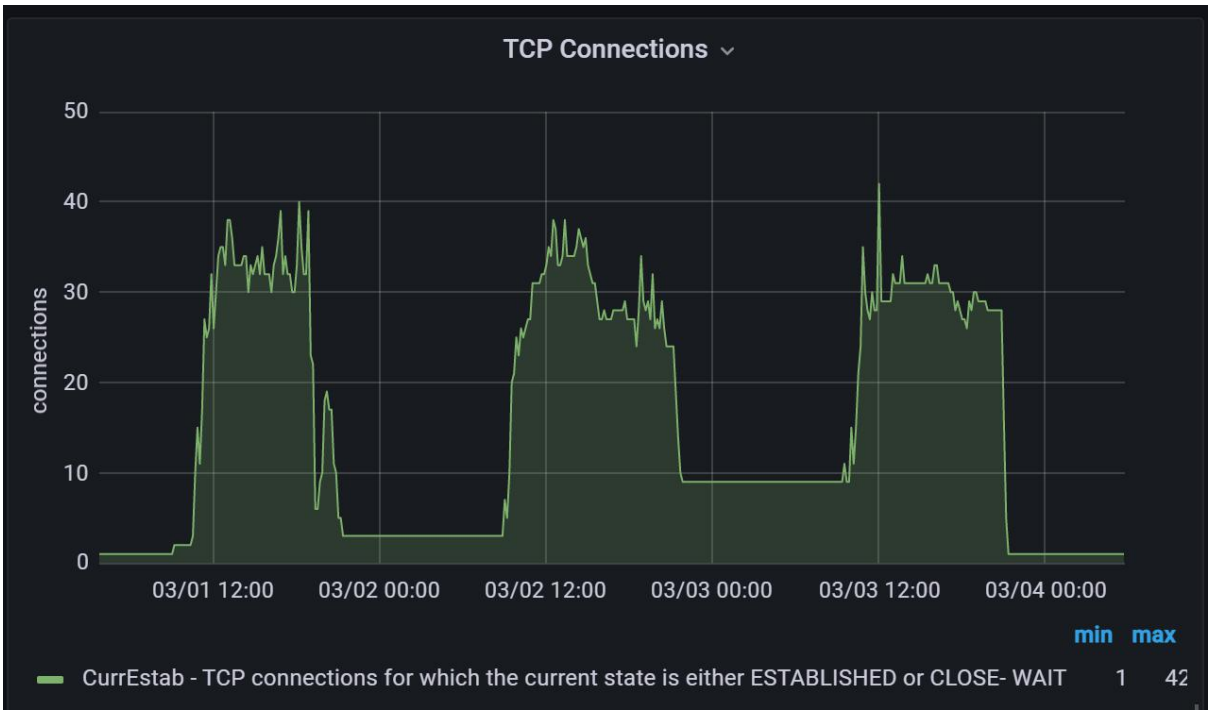
  As we had expected, there was not much traffic going through the P2P server, but it was very variable as devices came and went. This was more obvious during the first and second day, when a lot of testing was performed, while on the last day, when the showcase event took place, everything was fixed.

Figure 12: P2P Server Traffic




Network Traffic by Packets
75 p/s
50 p/s
25 p/s
0 p/s
-25 p/s
-50 p/s
packets out (-) / in (+)
03/01 12:00
03/02 00:00
03/02 12:00
03/03 00:00
03/03 12:00
03/04 00:00
ens3 - Receive 1.45 p/s 48.2 p/s 6.62 p/s 1.61 p/s
lo - Receive 0 p/s 0.149 p/s 0.00176 p/s 0 p/s
ens3 - Transmit 1.000 p/s 32.2 p/s 3.79 p/s 1.000 p/s
lo - Transmit 0 p/s 0.149 p/s 0.00176 p/s 0 p/s

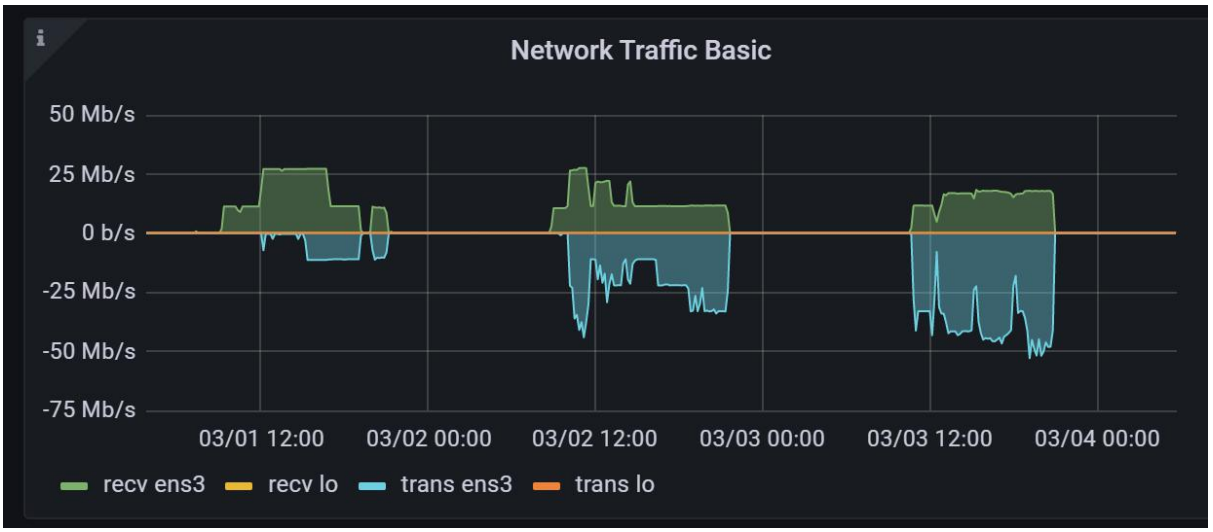

Sockstat TCP
50
40
30
20
10
0
counter
03/01 12:00
03/02 00:00
03/02 12:00
03/03 00:00
03/03 12:00
03/04 00:00
min max avg current
TCP_alloc - Allocated sockets 7 48 21.3 7
TCP_inuse - Tcp sockets currently in use 2 4 2.45 2
TCP_orphan - Orphan sockets 0 6 0.0337 0

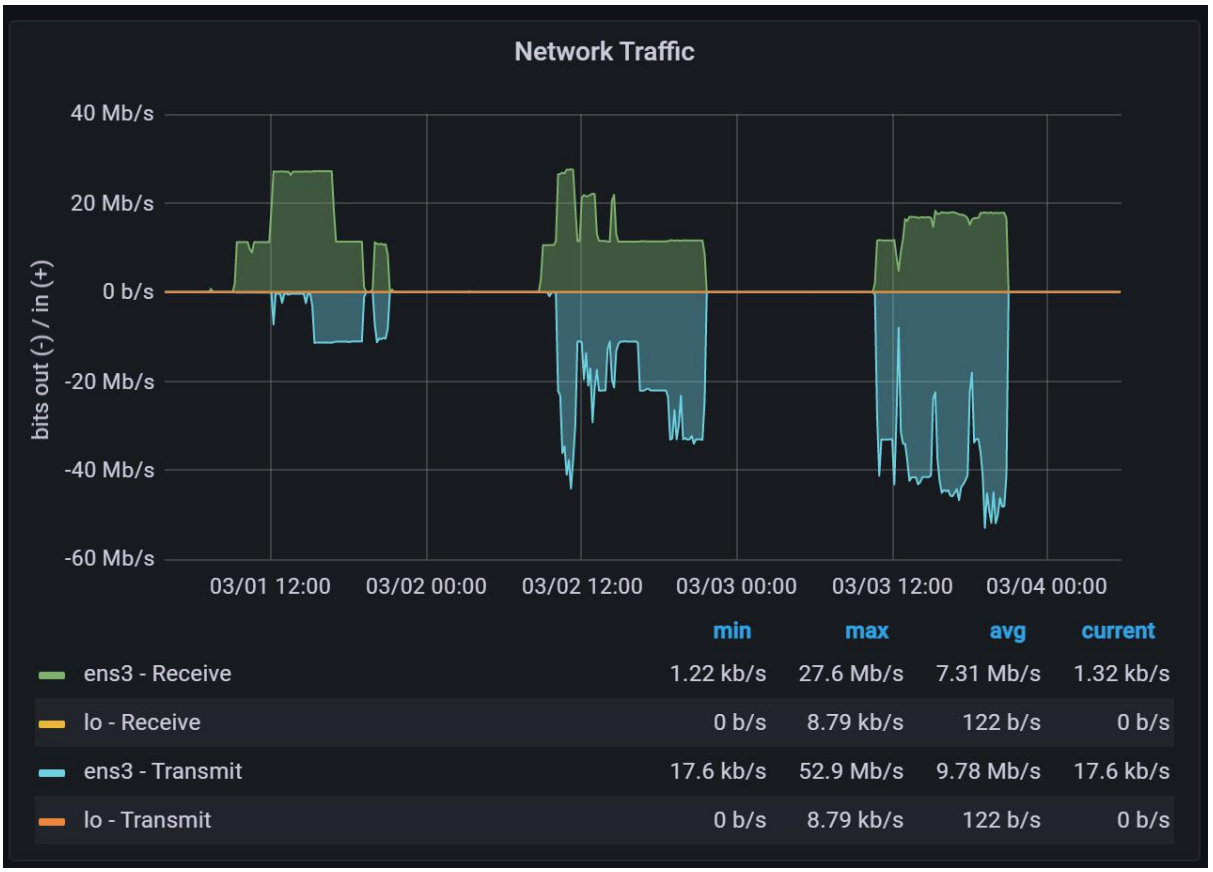


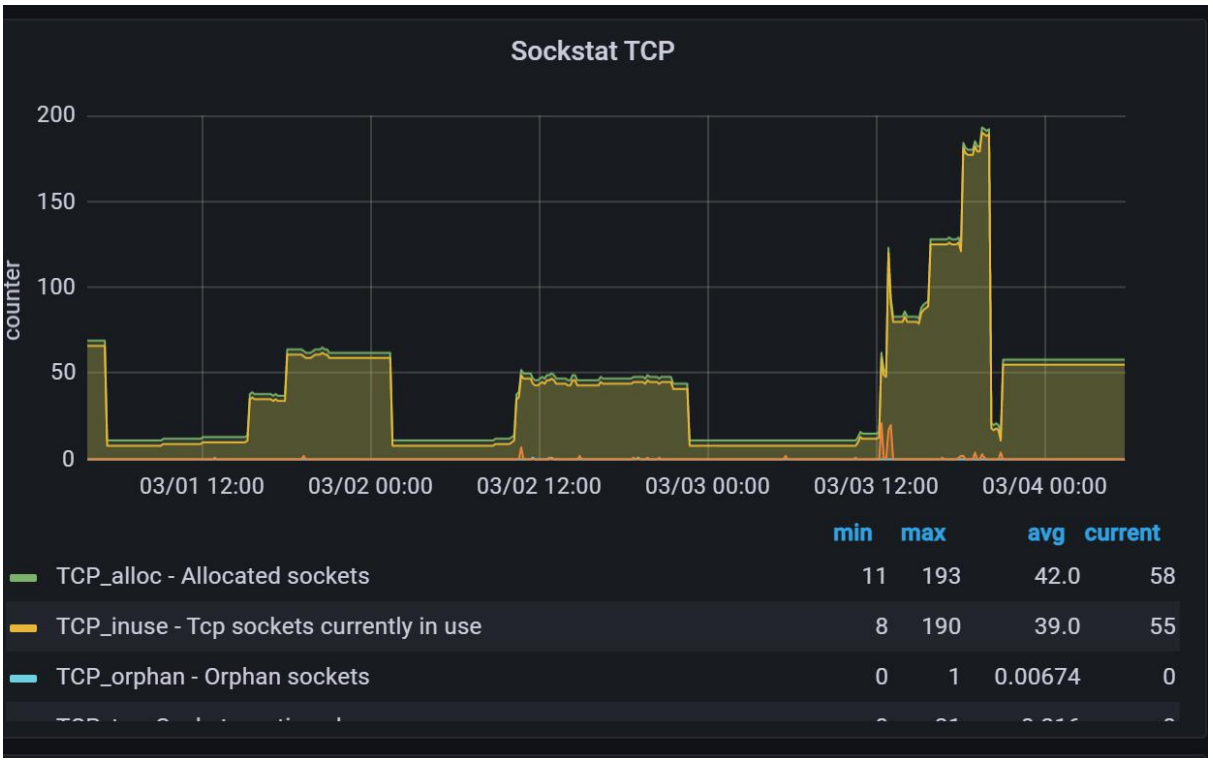
- Common Server

  The Common Server from the CSP was used primarily by UC2 and UC3 to ingest videos from the venues and then deliver it to different players and the CDN. This was made clear by the inbound and outbound traffic. Again, during the first two testing and setup days, traffic was fluctuating, while on the showcase day, the traffic was more constant, with an average of 20Mbps input traffic and 45Mbps output. The number of connections was also much higher, peaking at almost 180 during the showcase.

Figure 13: Server Traffic




Network Traffic
40 Mb/s
20 Mb/s
0 b/s
-20 Mb/s
-40 Mb/s
-60 Mb/s
bits out (-) / in (+)
03/01 12:00
03/02 00:00
03/02 12:00
03/03 00:00
03/03 12:00
03/04 00:00
min max avg current
ens3 - Receive 1.22 kb/s 27.6 Mb/s 7.31 Mb/s 1.32 kb/s
lo - Receive 0 b/s 8.79 kb/s 122 b/s 0 b/s
ens3 - Transmit 17.6 kb/s 52.9 Mb/s 9.78 Mb/s 17.6 kb/s
lo - Transmit 0 b/s 8.79 kb/s 122 b/s 0 b/s


Sockstat TCP
200
150
100
50
0
counter
03/01 12:00
03/02 00:00
03/02 12:00
03/03 00:00
03/03 12:00
03/04 00:00
min max avg current
TCP_alloc - Allocated sockets 11 193 42.0 58
TCP_inuse - Tcp sockets currently in use 8 190 39.0 55
TCP_orphan - Orphan sockets 0 1 0.00674 0

3.2. Public network integration status

3.3. Network Summary and Outlook

The 5G Network infrastructure deployed to support the 5G Festival project provided a blueprint for the setup required for such environments. It has identified key requirements, such as Multicast support both for audio (AES67) and video (NDI) in the uplink direction; this setup is currently not available in cellular systems. In addition, precision timing, on top of high bandwidth and low latency were key requirements that had not previously been considered as priorities. Such findings regarding these requirements could potentially drive future research and standardisation activities, with 3GPP Rel. 18 study items including PTP synchronisation over the air.

In terms of user experience, the network met the expectations, enabling artists and technicians to produce high-quality performance. Some of the learnings that we have gained during the project specifically relate to the interoperability of different systems. Implementation of the same protocol by different vendors may affect its performance and compatibility when putting the system together. This was something that we experienced when connecting the CISCO switch with a PaloAlto Firewall in order to enable PIM-SM for Multicast. Not all features of the protocol were available, so we had to re-draw the inter-site connectivity.

Although passing Multicast audio over 5G utilising GRE tunnelling was tested, further work is required to optimise that setup, including, for example, carrying the PTP signal for synchronisation purposes. In addition to this, further work is also required to optimise and automate the service deployment. Inter-domain orchestration could facilitate this with the tighter linking of public and private mobile networks. As 3GPP releases become widely available, features like Time Sensitive Networking (TSN) could be used for audio IP networks. Our key recommendation is to investigate further improvements on the Uplink and edge computing support for fast video encoding in order to minimise video latency.

4. UC1 - Beta Testing Completed

4.1. UC1 Video Testing

4.1.1. UC1 Beta prototype app and front - end description

The final UC1 prototype app provided an updated and easy to use User Iinterface (UI), which made it easy to start up any number of streams on any device. On the UC1 phones, two tabs were opened: one to broadcast the video of the device, and one to receive the stream from any other device. This uncoupling of the broadcast and playback allowed us to select which role each device played and to select the use it was meant for. For example, phones used to broadcast artists that were using the Nreal headsets were not used to receive any other streams; they were set as ‘broadcast only’ devices.

Figure 14: UC1 Artist Set Up

The ease of use of the UI was also ported to work on the Nreal headsets in an easy and intuitive way. The same pop-out menu was implemented to allowed multiple streams to run at the same time parallel to each other. The display of these streams was built in such a way to encompass the view of the artists without obstructing the user. The view could also be repositioned to allow customisation per artist. For example, the guitarist preferred the view being lower in his field of view, whilst the drummer preferred it higher. The updated CSP

provided controls to accommodate both artists' requirements to enhance performance whilst using the system and devices.

Figure 15: Artist wearing AR glasses

The reconnection feature meant that when the device was connected to the network, even if a stream dropped off from a remote venue due to any connectivity issues, the stream would be restarted automatically without any user intervention.

4.1.2. Video

For the final showcase 3 devices per venue, plus one Nreal headset per venue (AR glasses), were tested with great success. The CSP and the network proved stable throughout the 4 day trials and 4 day showcase days with a wide range of devices: 9 mobile phones; 3 Nreal headsets;3 linear camera encoding laptops; 3 linear camera decoding laptops; 2 projection decoding laptops and 3 overview laptops,all of which were running at the same time. Compared to the initial scope of the project, which included one Nreal headset per venue with a total of 3 devices sending and 3 device receiving content, the 23 devices setup we tested was almost an 8 fold increase.

Table 6: Video test list

UC1 Video test ID	Test description	Target KPI	Measurements	Comments
UC1VT1	Latency between capture and display		~100ms	The mobile phones proved to be the least latent capture devices tested.
UC1VT2	CSP encode, transfer, decode latency	50ms	28 - 68ms	
UC1VT3	Latency between capture and display on remote device		3-4 frames 128 - 168ms	
UC1VT4	Number of devices running on the network	3 devices	23 devices	

4.2. UC1 Audio Testing

4.2.1. Audio

4.2.1.1 Installation of semi-permanent PTP clock antenna at BDBF and Metropolis

PTP GPS antennas were installed at both BDBF and Metropolis studios and paired with Sonifex Grand Master Clocks (GMC's) to provide accurate clocking of the audio. While it's possible to tunnel clock between sites using the 5GF network, the use of local site clocking improves accuracy and stability. Following the trials in late 2021, both antennas were upgraded for higher gain output models in order to improve stability, as well as being repositioned to improve the line of "sight to sky". Poor line of "sight to sky" can result in weak satellite reception which ultimately affects the derived PTP clock.

Table 7 : Difference between poor (left) and good (right) GPS reception. Note the number of Satellites showing 0dBHz signal level

GPS Satellite Information	
Satellite 1:	7, 17dBHz, 18deg, 57deg
Satellite 2:	8, 0dBHz, 0deg, 0deg
Satellite 3:	10, 39dBHz, 38deg, 137deg
Satellite 4:	13, 0dBHz, 0deg, 0deg
Satellite 5:	15, 0dBHz, 0deg, 0deg
Satellite 6:	16, 48dBHz, 64deg, 187deg
Satellite 7:	n/a
Satellite 8:	n/a
Satellite 9:	n/a
Satellite 10:	n/a
Satellite 11:	n/a
Satellite 12:	n/a
Satellite 13:	n/a
Satellite 14:	n/a
Satellite 15:	n/a
Satellite 16:	n/a

GPS Satellite Information	
Satellite 1:	2, 36dBHz, 13deg, 112deg
Satellite 2:	6, 42dBHz, 17deg, 68deg
Satellite 3:	10, 0dBHz, 0deg, 0deg
Satellite 4:	11, 34dBHz, 7deg, 107deg
Satellite 5:	12, 50dBHz, 83deg, 56deg
Satellite 6:	17, 22dBHz, 1deg, 30deg
Satellite 7:	19, 44dBHz, 19deg, 40deg
Satellite 8:	22, 44dBHz, 28deg, 55deg
Satellite 9:	24, 45dBHz, 48deg, 125deg
Satellite 10:	n/a
Satellite 11:	n/a
Satellite 12:	n/a
Satellite 13:	n/a
Satellite 14:	n/a
Satellite 15:	n/a
Satellite 16:	n/a

4.2.1.2 Refinement of local audio systems (to incorporate local multitrack recording for UC2)

The audio system at the O2 Blueroom incorporated a Dante (audio network) connected multitrack recorder, capturing both local and remote audio. While no time adjustments on the remote audio were made, with any known network latency, post-production adjustments were easily achievable, providing high quality archive material or audio for further production prior to release.

4.2.1.3 Increasing local sample rate to 96 kHz for lower local latency (and higher fidelity audio capture for UC2)

During beta trials, tests were completed with high sampling rates with an individual local audio system. Whilst these proof of concept tests were not implemented during the final showcase, the testing proved that, given the right equipment, a high sampling rate could be implemented, which provided a higher audio fidelity for capture. With respect to latency, audio conversion is time-based, so a doubling of sample rate approximately halves the time taken for audio conversion. Within the context of the wider inter-site audio system, the small savings that could be made are relatively insignificant when compared to the intersite latency.

4.2.1.4 Soak testing of inter-site audio transport for stability and robustness

The stability of the intersite audio transport was crucial to the success of the audio delivery. During trials, we experienced unpredictable dropouts in audio network connectivity.

Extended testing and adjustment of the network showed that the stability of the PTP clock was a potential cause, which led to oure upgrading the GPS antennas, as detailed above.

Secondary to the GPS antenna upgrades, Access Control Lists were put in place to control traffic in the network, and PTP domains were used to ensure each site operated on its own PTP. Whilst all the switch configurations should have had limited PTP crossing the leased line, with such complex mixed traffic usage, these safety measures provided additional clocking separation.

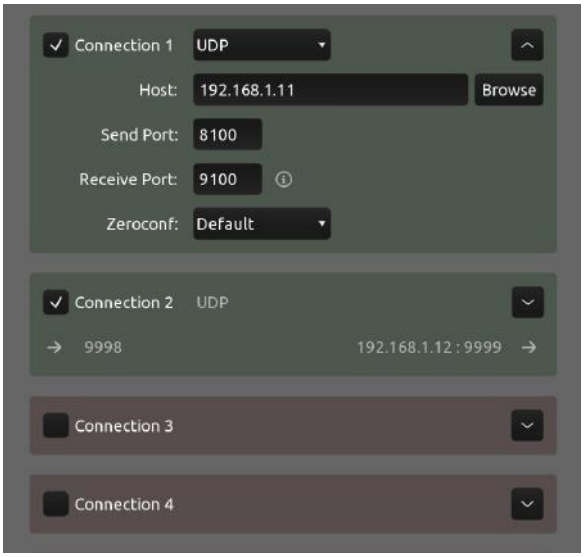
This clocking improvement, along with adjustments to link-offset and packet time values, improved the stability of the wider network and reduced potential for show stopping errors to a minimum.

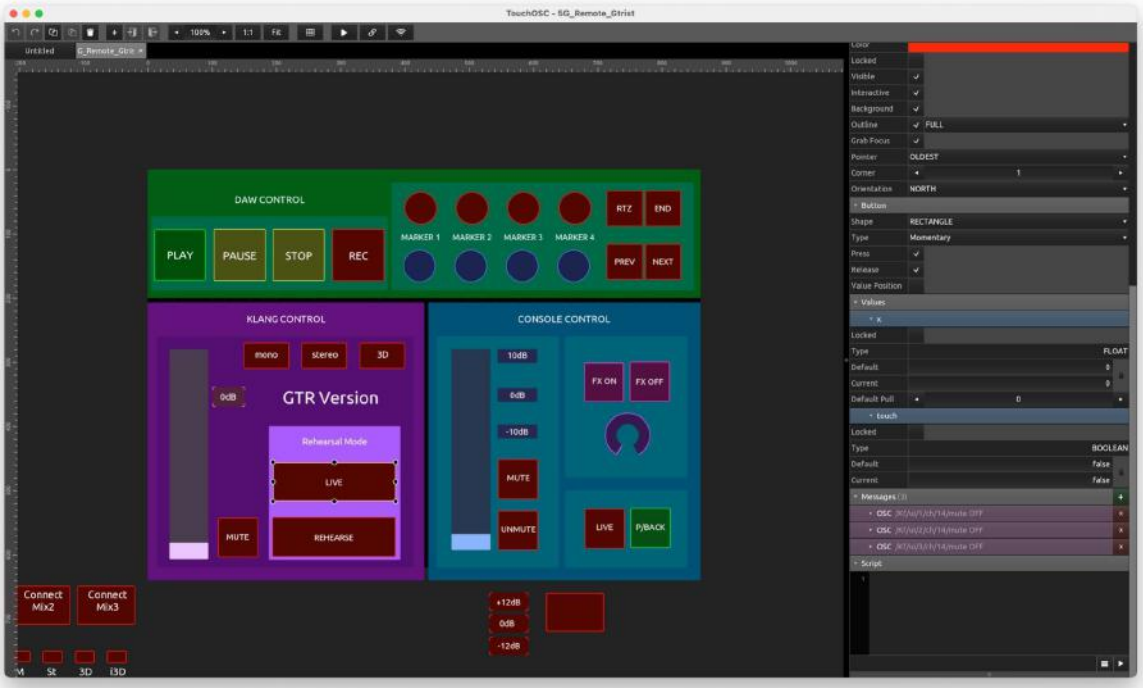
The ultimate stability of any future wireless 5G network will need careful design with respect to clocking and the balance between network configuration and bandwidth usage.

4.2.1.5 Remote control of local UC1 audio systems

During the delivery of the primary showcase, it was not possible to live test the remote control beta systems developed. Offline testing, however, proved the need for such systems in principle;future development work with musicians will be necessary to improve this kind of functionality.

Figure 16: UC1 Audio System Controls: (top) Example of multi-host connections for audio system remote control, (bottom) Development of Remote Control Interface





4.2.2. Comments on audio test results, yet to be tested or unable to test

4.2.2.1 UC1NReq#1

The immersive monitoring system negated the detrimental effect of the aforementioned latencies (as shown in MS4b/March Trials); network latency can be set lower, but the figure above gives the best balance between performance and stability.

The use of the Klang Immersive monitoring system added two highly important benefits to the audio systems in UC1 and UC3.

Whilst inter-site latencies would normally present musicians with challenges to play “in-time” with other remote musicians, the placement of sounds within the Klang, which created a 3D soundscape, made the experience feel much more “real”, as if they were sharing the same stage in a natural environment.In everyday life, our brains are used for handling and interpreting perceived differences naturally from sounds heard from all around us and are able to prioritise and make sense of the cues presented to our ears. This enables us to tell where that sound is coming from (localisation) and place it within the environment (room, hall, outside etc). This is how audio is perceived most naturally.

In a traditional ‘stereo’ monitoring system, the sounds are presented directly to the ear canal, bypassing several important ‘filters’ that enable us to make sense of the world around us.

Engineers have attempted to replicate these missing elements of information using different effects (e.g. delays, reverb) and dynamic frequency processing to help compensate. However, despite producing a technically good and balanced mix, some of these effects actually result in an unnatural input to the brain, which can affect how musicians hear themselves. This is especially true of vocalists because of the unique way they hear themselves through a balance between internal (bone transmission/resonance) and external (echos of their voice within a room/environment) audio cues. All of these factors result in a very low natural tolerance of electronic latency.

Utilising spatial modelling that replicates real world human auditory sense information with respect to level or volume, timing cues and frequency content, the latencies inherent in the inter-site audio links had far less impact when compared to a traditional stereo monitoring setup.

Secondary to this major benefit, the Klang Kontrollers provided all of the musicians with the ability to adjust their own monitor mix (the balance of all the different instruments that is preferable to each musician and usually handled by a monitor engineer, due to complexity of equipment).This added an important level of simplicity and autonomy to the setup, as well as changing the musicians' experience from a traditional technical live event, where they would make requests to a monitor engineer, to one that might be more aligned with a future commercial solution. This would be a solution where the role of monitor engineer becomes much more about servicing the needs of the musicians technically, with the artists themselvesooking after all aspects of their personal audio mix, resulting in a more immediate and intuitive experience where technology is secondary to creativity.

This solution would help bridge the transition from a rehearsal platform through to a final live performance; the experience would be a natural and intuitive encounter.

4.2.2.2 UC1FReq#2 (*The 5GF system shall be able to provide a monitoring mechanism for the audio signals*). The implemented 5GF Audio system utilised industry standard audio mixing and distribution components, connected and configured in specific ways for the project. While these components provided the means to monitor the audio signals, further work would be required to build audio monitoring capabilities into any potential commercial hardware.

4.2.2.3 UC1FReq#4 The AES67 documentation specifies 17 x packet time, which in this case = 2.125ms.It is uncertain where the original target KPI was drawn from, but is irrelevant with reference to the above specification and the equipment specification.

4.2.2.4 UC1FReq#7 (*The system shall support continuous monitoring of all its resources as well as means for self-healing in the event of faults or failures.*) Additional research and development work would be required to build resource monitoring and self-healing capabilities. During trials and showcase events, all resources were monitored, managed and fixed manually by specialist network engineers.

4.2.2.5 UC1FReq#14 (*The 5GF platform will provide the means for artists to connect to each other and start a collaborative session.*) When the 5G network technology exists to

support pier-to-pier connections, further development will be required to build systems that allow end users to start collaborative sessions. The trials and showcase events were all carried out over permanently connected end devices, utilising dedicated leased lines.As such, there was no artist involvement in the service connections.

4.2.2.6 UC1CReq#3 (*Music teachers teaching students in different locations, such as their homes or another pop-up location.*). This use case was not specifically tested, but in principle, UC1 tested and proved the capability of achieving this goal with the underlying technology. Additional front-end development would be required to build a teacher - student style interface.

4.2.2.7 UC1CReq#8 (*Ability for music teachers to teach students, in real-time via the network. This will be measured by survey.*) As above,his case was not specifically tested, but in principle, UC1 tested and proved the capability of achieving this goal with the underlying technology. Additional front end development would be required to build a teacher - student style interface.

Table 8: UC1 Audio KPI

Requirement ID	Description	Target KPI (if availabl e)	Last Measured Figure & Date	Final Measured KPI, Test Date(s) or Not Tested
	Testing completed/satisfactorily concluded Testing completed satisfactorily at this stage, requires further development or research Testing not required - subject of research or requires future development Testing not conducted			
UC1NReq#1	Audio Traffic Latency - Mouth to Ear - the time difference between the audio traffic is sent from one location and received at a second location over the 5GF network.	10 ms	10ms (network) + ~4ms (Self Latency)	As previous/ no change See Above 4.2.2.1
UC1NReq#3	Jitter - is the variation in the latency of packet flow from endpoint to endpoint.	2ms	Not Specifically Measured WRT Audio	Not Specifically Measured WRT Audio
UC1FReq#1	The 5GF system shall provide a synchronised click track running on the local platform will be locked to time of day from the 5G network.	N/A	March Trials	Tested June Trials

UC1FReq#2	The 5GF system shall be able to provide a monitoring mechanism for the audio signals	96Khz / 32bit		See Above 4.2.2.2
UC1FReq#3	The audio monitoring system shall include the ability for artists to be able to rehearse and collaborate with ultra low latency audio monitoring with bidirectional non time critical talkback function	N/A	All Trials	Showcase
UC1FReq#4	The 5GF system shall provide a master clock to synchronise all audio data.	<accuracy> 1µsec	8ns	8ns See Above 4.2.2.3
UC1FReq#7	The system shall support continuous monitoring of all its resources as well as means for self-healing in the event of faults or failures.	N/A		See Above 4.2.2.4
UC1FReq#10	The 5GF system shall provide the required audio equipment for each performer including microphones, in-ear monitoring (IEM), audio mixing consoles and corresponding peripherals.	N/A	All Trials	Showcase
UC1FReq#14	The 5GF platform will provide the means for artists to connect to each other and start a collaborative session.	N/A		See Above 4.2.2.5
UC1CReq#1	Artists playing together from different locations such as their homes, a recording studio, venue or and another pop-up location.	Minimum 2 individuals	June/NovTrials	Showcase
UC1CReq#2	Producers collaborating from different locations such as their homes, a recording studio, venue or and another pop-up location.	Minimum 2 individuals	June/NovTrials	Showcase
UC1CReq#3	Music teachers teaching students in different locations, such as their homes or another pop-up location.	Minimum 2 individuals		See Above 4.2.2.6
UC1CReq#6	Ability for artists to seamlessly play together, in real-time via the network. This will be measured by survey.	4 out of 5	All Trials	Showcase
UC1CReq#7	Ability for producers to collaborate together, in real-time via the network. This will be measured by survey.	4 out of 5	June/NovTrials	Showcase
UC1CReq#8	Ability for music teachers to teach students, in real-time via the network. This	4 out of 5		See Above 4.2.2.6

	will be measured by survey.			
UC1CReq#9	Musical genres as the subject of test for remote, real-time collaboration and/or teaching.	Minimum 3 genres	All Trials	Showcase

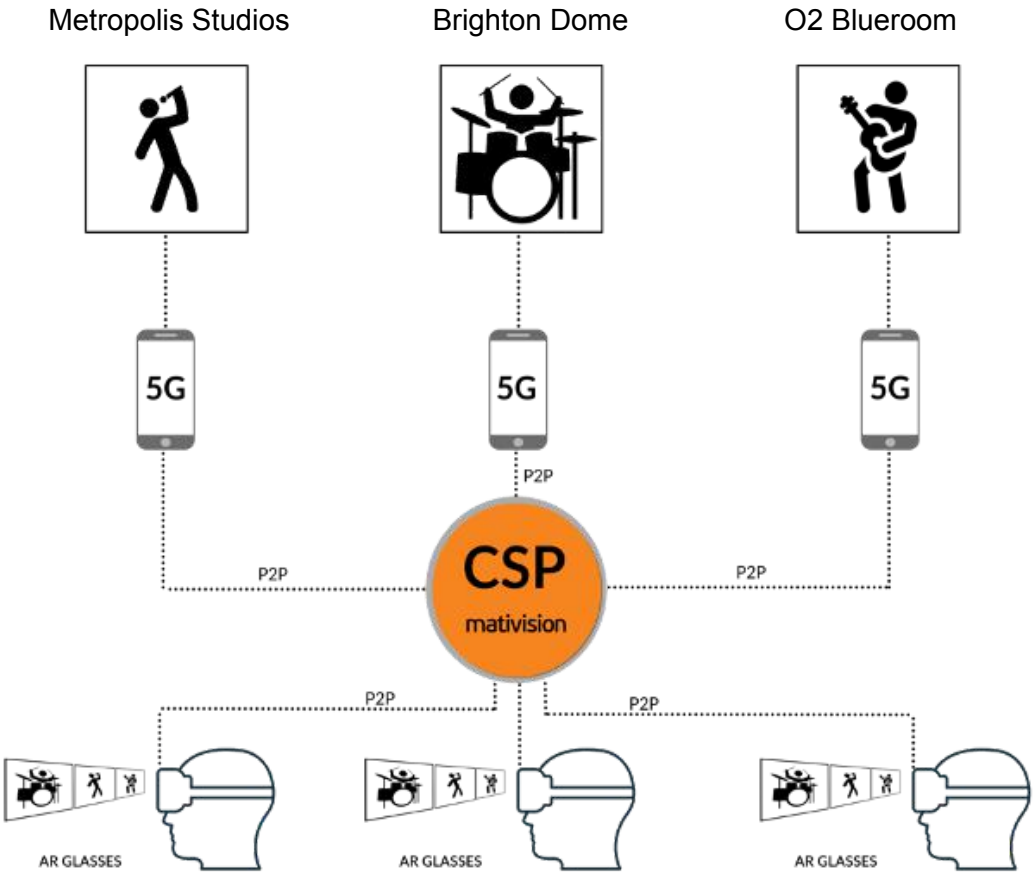
4.3. UC1 Project Summary

As detailed in the technical evaluation above, the Beta delivery of UC1 far excelled the original scope of the project. From the project R&D deliverables of 3 artists, using one camera set up and stream per artist, the consortium continually pushed the boundaries of the project, based on the stability and performance of the audio-visual streaming platform, and eventually delivered across 21 concurrent live artists, and 3 camera set-ups per location, totalling 9 across the 3 designated venues in a seamless and robust manner.

The potential environmental and commercial impact of concerts being mixed live from studios without having to move truck loads of kits and personnel cannot be underestimated. In the context of the project, this was illustrated by the immersive audio mix transported from Phil Wright, located inMetropolis Studios, to the live event at the Brighton Dome.

When Over-The-Air (OTA) 5G technology and supporting services exist, the low latency performance and freedom to connect from anywhere (with suitable 5G coverage) will offer significant advantages over the current high latency fixed internet solutions offered.

Figure 17: UC1 Architecture



Audiences of the Future (3rd Person Professional Perspective) - Nick Young

All of the musicians felt that the technology developed as part of the 5G Festival project is a game changer for the industry. The ability to play in real time with other artists, who could be on the other side of the world, was a real eye opener for them, and instantly impressed even in the early development days. What was interesting was that facilitating hybrid live events (UC3) was not the first choice of application they would have considered, coming further down their lists. They all said that its application in rehearsals and studio sessions was of more immediate interest, as this is often the part that is expensive and time-consuming if people are having to travel with instruments/kit. The ability to dial in, jam, rehearse, tweak and prep, with little to no cost, genuinely excited them. Whilst there has been a pandemic induced paradigm shift to doing stuff via Zoom or equivalent platforms, everyone bemoaned the poor quality, and lag of these offerings as real barriers that prevent genuine artistic collaboration.

The audio latency was minimal, to the point of being virtually real time, and therefore facilitated the musicians creating and playing together. The video latency varied and sometimes lagged (although I believe this was down to the inherent latency in peripheral devices, camera hardware etc., and not any issues with the Common Service Platform (CSP). It did facilitate a sense of being ‘with’ other artists, though, and this was welcomed. The spatial set-up of the video feeds and virtual environments could benefit from artists’ input in order to better recreate the sightlines and natural feel of actually playing together - both in the Nreal glasses and the physical screens they had in front of them. This was reviewed and adapted across the project to aid the artist experience, and will need continued refinement and development to suit all collaboration use cases. There is a sense of ‘giving up’ part of the real world for the virtual world, which currently creates interference in the creative act - but this is also partly due to the novelty of the experience. The artists who were given time to play with, familiarise, and understand how to manipulate the set-up themselves were keener to use it in front of an audience than the others, who were wary of anything that could disrupt their playing.

There was a strong belief articulated that there will always be a subtle but tangible difference between the physical and the digital, no matter how good the technology becomes, and that the human connection from physical proxemics, and what it allows, is difficult to replicate - e.g. facilitating improvisation onstage. However, it is worth acknowledging that this feedback was given during a test project, and that as the technology progresses and (as importantly) it progresses hand-in-hand with the creative understanding and stretching of it, then many of these concerns may fade, if not disappear. Realistically, the virtual is a long way from being a full proxy for the real, but if the tech allows for greater access, and enhanced experiences in other areas then it is worth it as an augmentation of the creative process and experience, rather than a substitution for it.

The creative direction by the Musical Director (MD) was enhanced in a number of different ways, but also threw up some challenges. The ability to work with so many artists is increasingly rare due to shrinking budgets and rising costs, so this was a really exciting and fun project for everyone in that respect. The comms in real-time were excellent and allowed for everyone to be 'in the room' in a way that would have been difficult had it been in person due to the sheer number of artists and associated costs & logistics. However, the lack of physical presence and proximity was sometimes, understandably, a limitation to the methods of communication and feedback that the musicians are accustomed to. This meant more time, work, and different methods of direction were needed to achieve the vision of the MD. Again, a period of adjustment and learning for the technical teams through feedback would most likely address many of these issues over time.

Examples given of potential live show applications included the ability to present a show/experience to an audience that may not be possible normally due to budgetary and/or logistical restraints. This could be having a string section that only play on one or two songs; a 'big name' musician doing a guest appearance from across the world; and, of course, the artist who can't make a performance physically due to travel/illness/etc being able to be there negating having to cancel or re-rehearse a stand in.

The showcase would have benefitted from an artist acclimatisation-to-tech period and a separate technical rehearsal from the dress/run throughs. This would have allowed them to ease into this new world in a way that gave them creative and personal agency, and also, practically, allowed them to set up the kit according to personal preferences. But, to go a step further, it would be better to involve the artists from the very beginning of the design process. As one performer feedback "The tech is a tool. Art is not a utilitarian purpose. It's important to remember the distinction." This came with a warning not to be "distracted by conscience and cost savings where avoidable".

Each of the individual elements were handled by top end creative and technical teams who worked hard and well to pull the project together. That said, a lack of a Creative Director role, whose job it would be to oversee all of the disparate elements under a unifying creative vision, meant that familiar methods and set-ups were sometimes fallen back on, where a more innovative creative approach could have been taken. Where the back-end technology and its uses gave us a glimpse of the future, the setup and presentation at times felt overly familiar and contemporary. Someone to conceptualise and oversee the creative development of the project as a whole would be strongly recommended for future iterations. This way, the physical and virtual spaces, the artists within them, and the audience interacting with them, could be totally reimagined for a more immersive blended experience.

5. UC2 - Beta Testing Completed

5.1. UC2 Video Beta Testing

5.1.1. UC2 Beta prototype app and front end description

For UC2, the synthetic environment, the real-time engine brought together 9 concurrent artists in the same graphics environment, rendering at the same time and overlaid over the rendered environment.

Figure 18: UC2 Synthetic Environments & Devices

The CSP was used to connect via P2P to each of the concurrently rendering devices; each frame was grabbed and mapped to the real-time graphics environment. The synthetic environment was rendered at 2560x1280 providing 50% more resolution when compared to a Full HD stream.

The stream was pushed to the local CSP Virtual Machine (VM). The local VM provided a low latency HLS stream for local devices to consume, such as the DC Oculus Quest devices used in the Founders Room, and also pushed the stream out to the cloud platform.

The local VM segmented, packed in multiple small segments that provided the low latency also used by the UC3 linear camera feeds pushed through the VM. This allowed concurrent viewing of both the UC2 and UC3 in the Founders Room, with immersive audio synchronised to both viewing methods (TV, VR HMD).

Figure 19: VR headsets

The feed that was pushed to the cloud platform was transcoded to multiple renditions, with different bitrates to accommodate a breadth of end-user connection bandwidths. The audio was not tampered with and was passed through without any transcoding to ensure there was no loss in audio quality and no intermediate processing that would tamper with the audio mix.

Figure 20: Virtual Stage presenting all the video streams

The audio received at UC2 via the Audiomovers listen to application was set to 0.1 sec latency, which lined up with the capture latency of the devices running through the CSP, achieving synchronisation with minimal fine-tuning inside the real-time graphics engine.

5.1.2. Video (description and test/feature lists (tested or to be tested)

Table 9: UC2 Video KPI test list

UC2 Video test ID	Test description	Target KPI	Measurements (if already tested)	Comments
UC2VT1	4 channel audio received and streamed through the synthetic environment engine.	4 channels	4 channels	
UC2VT2	Target resolution	1920 x 1080	2560 x 1280	
UC2VT3	Target network	cloud based	local streaming and cloud based	
UC2VT4	Synchronisation	2 frames	<=1 frame	

5.1.3. Web-based Application & Features

Front-end application for remote-audience viewing of audio-visual streams

The front-end web based application was designed to provide a bridge between Use Cases 2 & 3, allowing users to discover details about the festival, purchase in-person or remote-only tickets for the festival itself, and for viewing both immersive and linear streams of performances.

This functionality was provided across two core pages:

- **Home page** - The starting point for the web app, providing details about the festival, videos and links to purchase tickets.
- **Live page** - After purchasing a ticket, users are directed to this page, which provides links to live streams.

Two streams were provided on the “live” page: one offering a 360 immersive environment, compatible with browsers and Virtual Reality headsets, and the other providing a linear, standard video broadcast.

Access to the streams was controlled by access codes provided with a ticket purchase.

For the completion of the beta prototype, the following enhancements were made to the existing application built for previous test events, to provide a more complete product for the showcase events:

Design - Introduced a new, simplified front-end design to all pages across the app.

This followed the print design guidelines for 5G Festival supporting material.

Error handling - Enhanced the existing error management across both video players, increasing the number of self-resolving errors and user feedback for remaining errors.

Session transfer - Introduced session management features to allow users to recover or transfer previously active sessions from other devices and browsers.

Session management

Storage - Validating access codes and recording their sessions in a persistent database.

Existing sessions - Preventing access if an existing session is active for a supplied access code.

Access removal - When a session is transferred to a new device or browser, previous sessions are closed, preventing multiple active sessions per access code.

Security

Raw stream - All stream file requests are passed-through the apps back-end server to prevent the raw stream URL being exposed to the front-end.

Access control - Whilst retrieving the raw stream file, the access code session is also validated to prevent hijacking or to handle transferring.

Load-testing

Pre-event - Tested with multiple concurrent users to ascertain server capabilities and suitability for the showcase event.

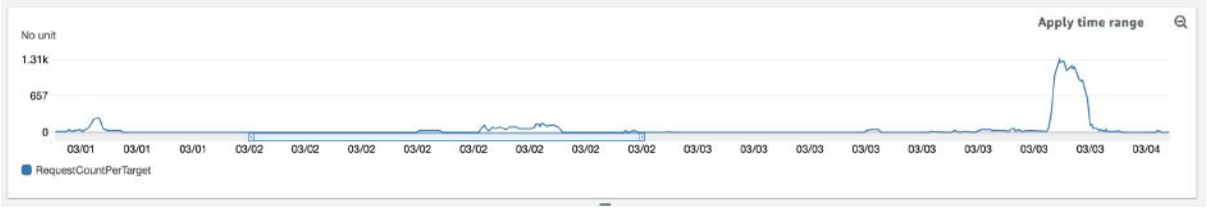
- 1,000 concurrent users accessing the stream
- If over 70% usage increase server nodes accordingly
- Test caused an increase to 5 nodes

Based on these tests and expected users for the showcase, we set the server to have **3 nodes** always running and a maximum of **10 nodes** to scale to.

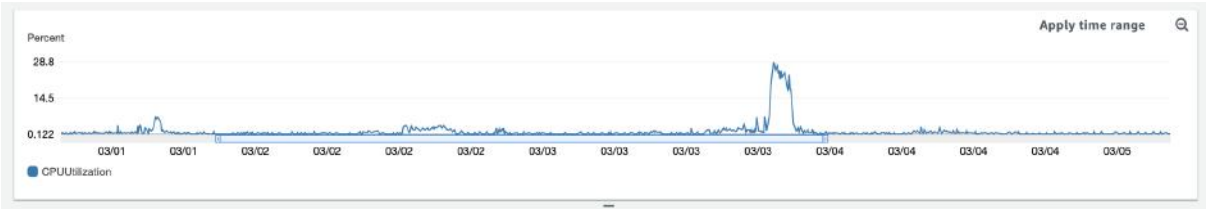
During showcase - At the time of recording, a total of **1,132** unique access codes hadbeen used to access the live streams.

Figure 21: Web-based Application Data

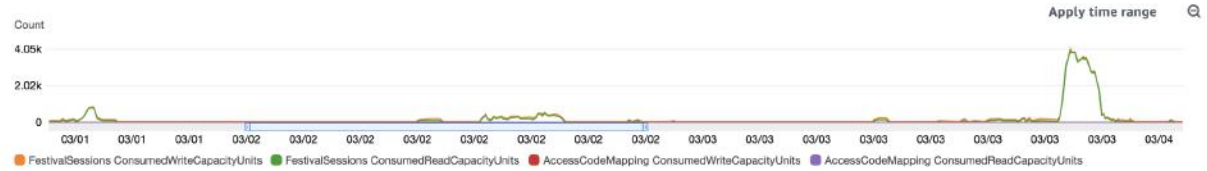
CPU usage



Request count



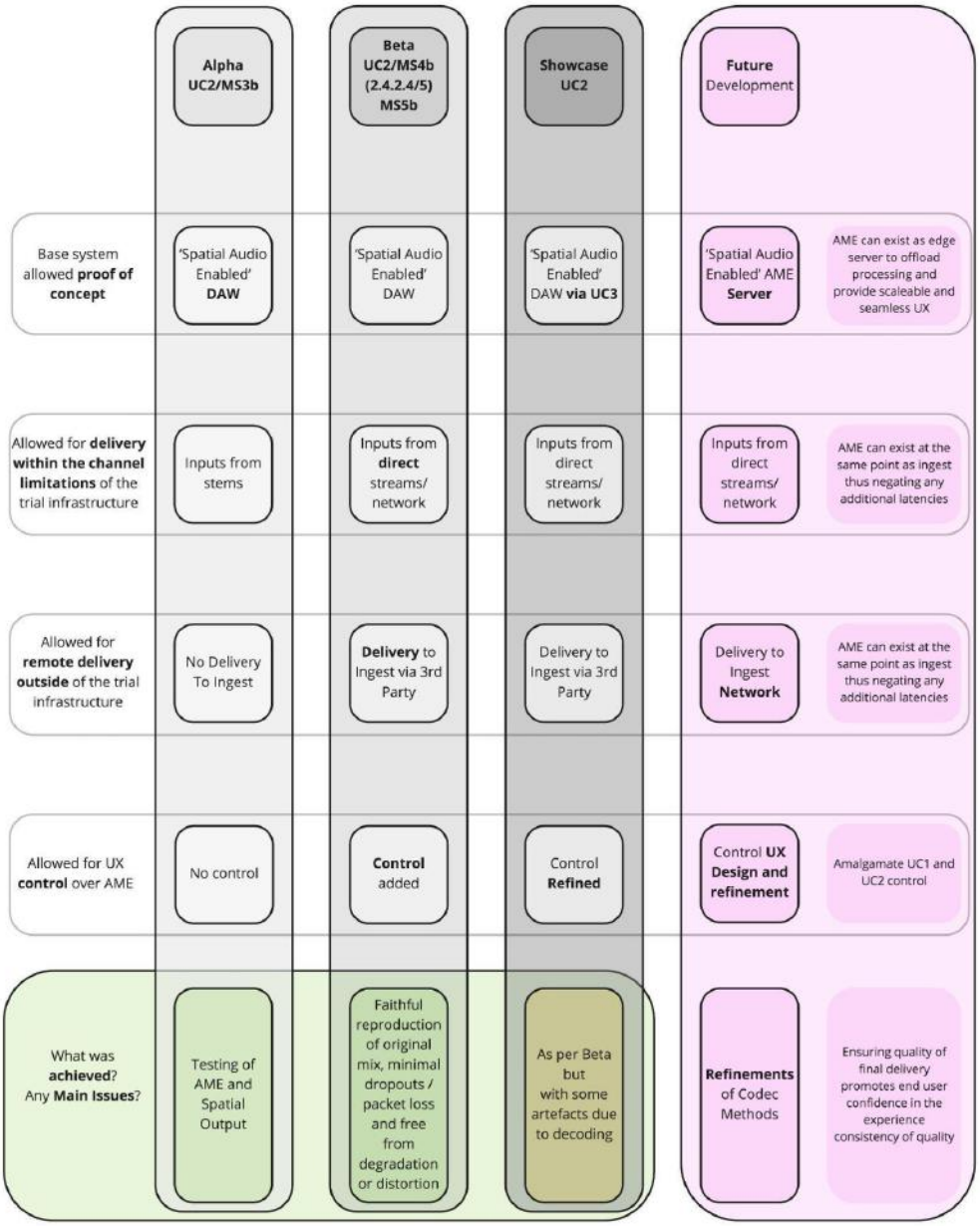
Database metrics



5.2. UC2 Audio Beta Testing

5.2.1. Audio

Figure 22: UC2 Audio Description



5.2.1.1 Incorporating local multitrack recording abilities to enable artist to mix outgoing stream (Mix Foldback for stream monitoring - UC2 specific)

Also see above Section 4.2.1.2

The requirement for this option (to incorporate local multitrack recording abilities to enable artists to mix outgoing streams) comes from UC2 as UC1 and currently it's not required. However, it is needed to build it from the ground up, and did affect the decisions made within the UC1 context - hence this spans both user cases.

The main reason for adding this capability is so that a 'nominated artist or musician' can act as the overall mix controller for audio output to stream (or to recording in the case of A&R or archival type scenarios). Even though most of this would be automatic via the UC2 AME, it would still be necessary to have a qualitative overview type control over the final mix, and the ability to switch this 'automix' out when presented in 'Engineer Mode'.

As this artist is likely playing with the band, a method is required whereby they can not only perform and adjust their own In Ear Monitor (IEM) mix, but can also record/playback passages of songs so that they can Quality Control (QC) the mix going to the stream without it getting in the way while they are performing.

This maintains the autonomous ability/capability of the platform, whilst also opening up the option to outsource this role to an MD or Engineer, should there be budget or requirement, who then become that 'nominated' person.

There is a clear need for this requirement in future iterations of the platform, whilst also looking to provide a service for archival and A&R Teams.

5.2.1.2 Higher fidelity audio capture (maintain quality to end consumer via stream)

Also see above Section 4.2.1.3

In addition to the above, the ability to record/stream audio at 96kHz/32bit is required to maintain the quality and consistency of the platform across many different types of user and abilities. It is not expected that most people using the platform will have deep engineering knowledge or experience, and indeed one of the aims of the platform is to offer a 'technology free' experience, where the artist is not distracted by the technology and able to maintain focus on the art. The ability to delve deeper into the controls or hand these off to another entity should exist to make the most from the experience. This should not, however, hinder the experience at the outset.

96kHz recordings are a requisite of many A&R type departments in order to maintain high quality and roll over into the studio if so required. This adds to the security of future proofing abilities, even for archival purposes.

The higher resolution also facilitates the greater perception of spatial resolution within the final mix output.

32bit files/file streams serve no real purpose in the output stages, as these represent dynamics well beyond the scope of human hearing.lectronic input stages, however, benefit from the 32bit structure as sounds in the real world have dynamic ranges that can exceed the capabilities and noise floors of 24bit recording. The reasoning behind utilising 32bit structure here is primarily concerned with the point of view of the consumer rather than someone like a professional audio engineer - it takes the emphasis off the artist to maintain the sometimes delicate balance of gain structure and maintains that confidence in the system and overall quality control of the platform.

5.2.1.3 Remote control of local UC1 audio systems (Recording and outgoing Mix Foldback Interface for UC2 stream monitoring)

Also see above Section 4.2.1.5

This facility is required as part of 5.2.1.1 so that the nominated artist can be in control of the recording and playback process.

As mentioned in section 4.2.1.5, it was not necessary to progress this capability (remote control of local UC1 audio systems) past proof of concept and establish that it is a valid part of the overall system design/implementation. However, it has been recognised that this requires further development and UX design/feedback sessions to carefully fit homogeneously within the overall platform interface and switch seamlessly and effortlessly between UC1 and UC2 ‘Modes’, so as not to detract from the creative process, and that this will be beneficial to consider for further deployment.

Figure 23: UC2 Audio Device Screenshots

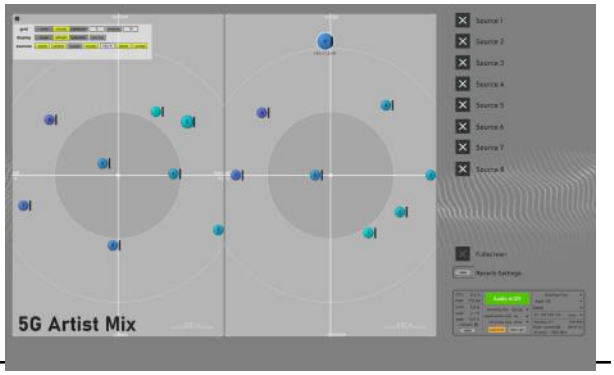
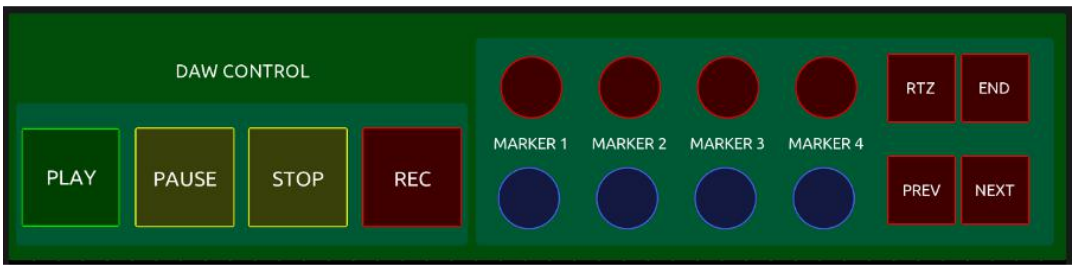
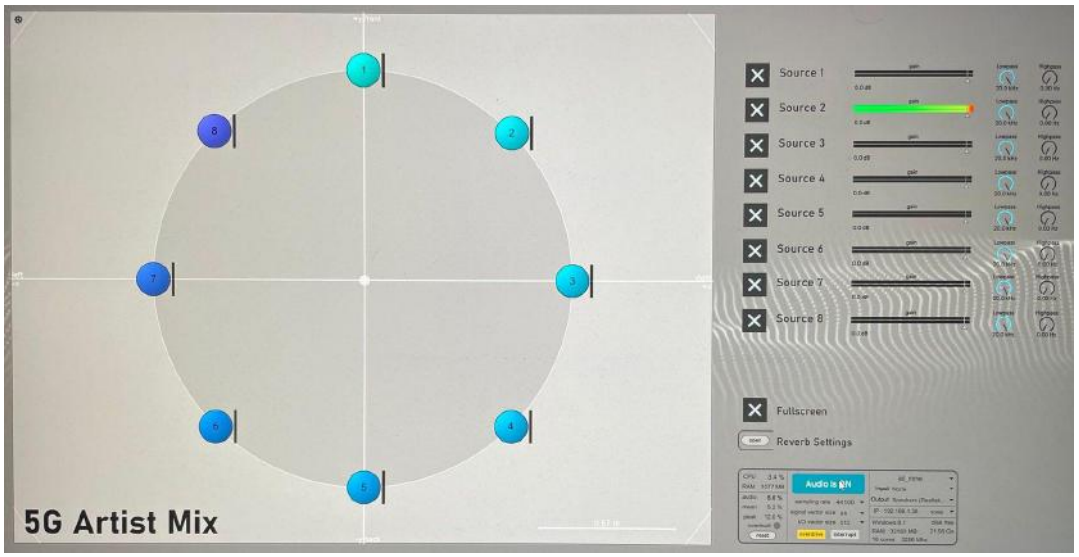


Figure 24: Imagery showing Further R&D work is necessary to bring together the separate UX elements



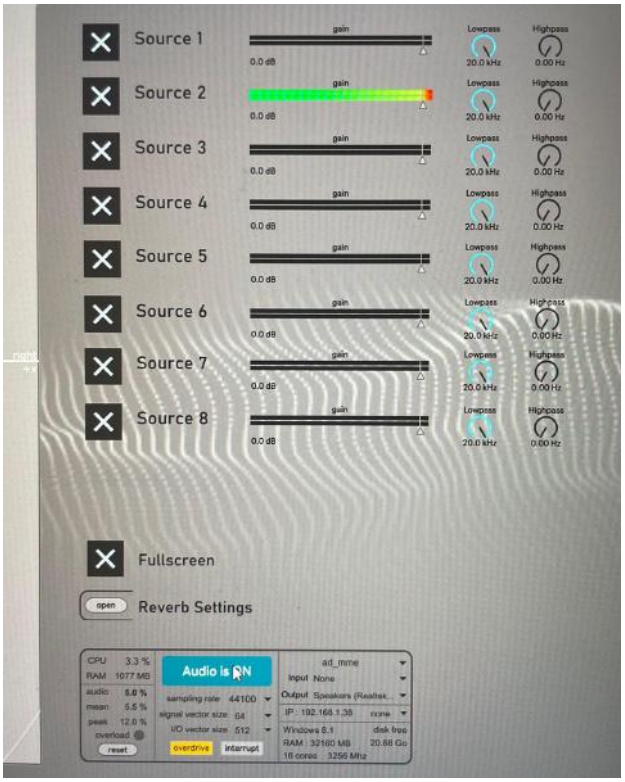
5.2.1.4 Revision of UC2 Audio Mix Engine and Control

Figure 25: Screenshot showing added level control of AME



Further and continuing development of the UC2 AMECI, including adding level control and improved usability (following feedback from June trials), added the ability to control levels and bring UC2 to a satisfactory status to prove concept within the remit of this project.

Figure 26 : Screenshot showing level control and resource monitoring of AME



This development would need to be continued in conjunction with the CSP UX interface to amalgamate and bring both under one UX ‘theme’ and add in the requisite control to enable the features mentioned above, where it still maintains a degree of separation between operational modes, i.e. UC1 control = artist's own mix, UC 2 control = mix to stream; both are doing different things and, as such, require different controls/methodologies. We recommend that the interfaces should look slightly different so as to avoid confusion, but that they remain somewhat similar for familiarity purposes.

Further research and development is required to implement the automatic spatial mix engine in a server format, and the AI implementation elements to drive the decisions made within the engine; there is the potential that the processing of this would need to be offloaded to an edge server/VM so as not to tax the user machine. If so, 5G would help with both ad-hoc connectivity to the server, slicing to ensure QoS and the speed necessary to make this processing ‘real time’.

The AI engine development needs to be fed from a large amount of listening tests and feedback, as well as real-time feedback from end users/content consumers, taking into account the amount of ‘manual control’ applied (subjective qualitative tests).

5.2.1.5 Audio Engine>Frontend Application Integration/Audio Rendering

As per MS5 document, initial tests were to incorporate 1st Order ambisonics with further tests in Nov to increase to 3rd Order resolution. However, the web browser approach posed an issue with delivering this.

Whilst streaming engines are capable of ingesting the 16 channels of audio required for 3rd Order delivery, channel counts in web browsers currently do not support greater than 8 channels in single delivery format. As mentioned in MS6, it is theoretically possible to 'stitch' two streams together.Guaranteeing the synchronisation of these streams, however, is not currently possible.

It is possible to deliver this channel count via a dedicated/downloadable app, but this would steer away from the accessibility afforded by using a web browser app based approach.
Further research and development would be required to consider and consolidate various approaches for future delivery options (see also UC3 Dolby Integration), and this may crossover with the ability to use true object based delivery, rendering the ambisonics delivery method obsolete for these purposes, which was included in the original scope for this project

Alignment of Audio and Visual Elements - Positioning

Matching visuals and audio positioning is paramount to the overall feel and envelopment of UC2. With the synthesised environment engine (Mativision/Visual) in development, the main focus was to prove concepts and have a working system with which to develop further integration. In tests and the Showcase, these two parts were produced separately and positioning of the audio was not necessarily linked up with the position of the visuals or the location of the musicians, as they were presented in a static line across this environment and would not have made for an interesting and engaging audio mix. This would obviously need development in the future, once the synthesis and audio engines have been developed to be more in line with the visioning for this use case, at which point the environment as a whole will be much more cohesive, realistic and engaging.

From these trials, it is evident there would need to be a number of considerations during this phase, which would also need to reference UC3 requirements. A big plus point of having these two user cases developed concurrently within this project was to be able to see alternative uses/required features that may impact on the design of the other, with various elements of the UX design and featuresets being co-developed across both use cases to solidify the link and crossover points between the two.

The UC2 AME is an automatic mixing system approach that can be manually tweaked by the musician or artist to taste a simplified UX approach that offers deeper 'under the hood', or more discreet, controls, if required - but these are not necessary to achieve a quality result.

The two engines (A&V) would require the linking of metadata between the audio and visual elements to allow for a quality result, and would need careful and thoughtful design as to which parts need to be linked and which to leave as a separate control, or whether this can be user-selectable.

As a contrast UC3 takes an engineered approach and therefore requires different tools to complete the task (see Section 6.2)

Fidelity - (Mix integrity) AME>Player Render

Whilst positioning and referencing worked well, there were slight degradations in the output delivery of the audio quality, mainly due to transcoding/bitrate/player limitations etc, rather than the stream. These elements would require further testing and development to deliver the best quality possible from the stream>player render. It is important to deliver this level of quality, as artefacts within an ambisonics mix can weaken the perception of the soundfield/spatial awareness. It is thought that the increased bandwidth and speed of 5G would offer a platform to deliver the highest quality and bitrate possible, maintaining that integrity.

A fully object-based render system is less susceptible to these soundfield collapses/spatial cue losses as the render is delivered at full quality at the point of consumption. However, the material may still be susceptible to bitrate change/artefacts if not handled correctly, but this would be accounted for through the developments undertaken in the UC1 .

5.2.2. Comments on audio test results, remaining to be tested or not able to test

5.2.2.1 UC2NReq#6 (Jitter - is the variation in the latency of packet flow from endpoint to endpoint.)

Whilst jitter, which refers to the variation of timing accuracy, on the audio network was not specifically measured, some of the audio dropouts experienced during trials were indicative of jitter. With the network being clocked to PTP via GPS, and the issues with the GPS reception subsequently found and resolved (see UC1), it is likely that inter-venue jitter was not a problem and audio network timing accuracy was not a significant issue. In future trials, jitter would be measured to substantiate this.

5.2.2.2 UC2FReq#4 (The system shall support continuous monitoring of all its resources as well as means for self-healing in the event of faults or failures.)

Additional research and development work would be required to build resource monitoring and self-healing capabilities. During trials and showcase events, all resources were monitored, managed and fixed manually by specialist engineers. (see also 4.2.2.4 above)

5.2.2.3 UC2FReq#9 (The 5GF system shall provide a cross platform player for users to watch the synthetic 360 Video stream.)

As per below, this was tested satisfactorily for the purposes of this project, and will require further (possibly ground-up in certain areas) development to take through to a commercial stage.

5.2.2.4 UC2CReq#1 (Audio head tracking with a high res Ambisonics Mix to create a localised experience.)

Whilst this was thoroughly tested during the pre-trial period, trial and showcase events illustrated that the increased spatial resolution that 3rd Order offers was not able to be contrasted and compared with the 1st Order base concept development (as per above mentioned reasons).It was shown to work convincingly, however, and would need more development in both delivery formats and player decode/render to work fully with 3rd Order resolution; it is not expected that this would be difficult to achieve given a few key breakthroughs. Although it is useful learning, it is anticipated that the time taken to prove this resolution increase would be better spent using this base development as a grounding for proving concept, and the thorough development of a more commercially viable future oriented hybrid or a true object based system. It has been tested satisfactorily with regards to the outcomes of this project.

Table 10: UC2 Audio KPI

Requirement ID	Description	Target KPI (if available)	Last Measured Figure & Date	Final Measured KPI, Test Date(s) or Not Tested
	Testing completed/satisfactorily concluded Testing completed satisfactorily at this stage, requires further development or research Testing not required - subject of research or requires future development Testing not conducted			
UC2NReq#3	Audio latency to match video latency provided by Mativision.	N/A	500ms MS4b	348ms/ 20.5 Frames @60fps Showcase
UC2NReq#5	Bandwidth to accommodate Stereo, Binaural & ~~4th~~ 3rd Order (see MS5) Ambisonics audio stream	200Mbps	9.9Mbps/ 8ch Stream	No change from

			x4 = 39.6Mbps	previous
UC2NReq#6	Jitter - is the variation in the latency of packet flow from endpoint to endpoint.	2ms	Not Measured With Respect to Audio	Not Measured See 5.2.2.1 Above
UC2FReq#1	Audio and Video to align within the frame rate of the final delivery	Within 1 Frame	500ms/ 29.4 Frames @60fps MS4b <=0.5 Frame Difference	348ms/ 20.5 Frames @60fps Showcase <=0.5 Frame Difference
UC2FReq#4	The system shall support continuous monitoring of all its resources as well as means for self-healing in the event of faults or failures.	N/A		5.2.2.2
UC2FReq#9	The 5GF system shall provide a cross platform player for users to watch the synthetic 360 Video stream.			5.2.2.3
UC2CReq#1	Audio head tracking with a high res Ambisonics Mix to create a localised experience.	N/A		5.2.2.4
UC2CReq#5	The 5GF should enable group online viewing of artists as a social activity.	N/A	Nov Trials	Showcase
UC2CReq#7	The 5GF should enable a collective viewing experience in a single room, eg VR Lounge	# of users (15)	Nov Trials	Showcase

5.3. UC2 Project Summary

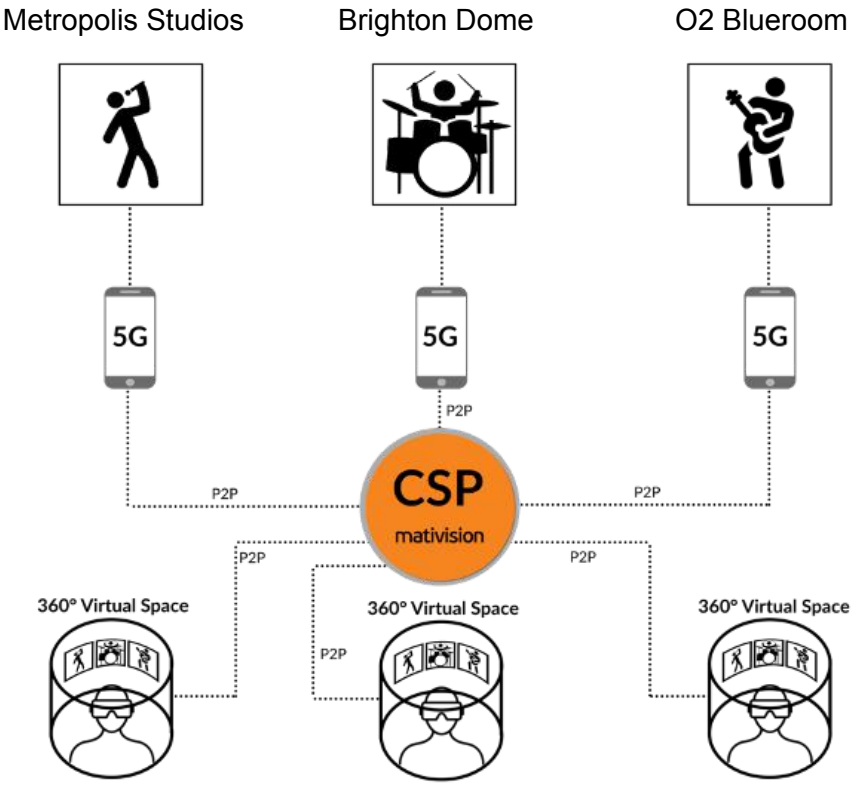
Through the CSP delivery of all artist streams and devices, including additional linear camera streams, the content was able to be directed and deployed to the remote audience's preferred peripheral device (VR headset, smartphone, laptop) via the O2 web-based URL application.

This demonstrated fully the capability to provide an enhanced experience of the live event to a remote global audience seamlessly to the concurrent event. This provides a significant opportunity for UK venues, of any size, to engage a wider audience without the need to travel, and would have the potential to hugely increase revenue streams.

It's important to continue to explore the curation of 'enhanced' events for remote audiences across different live events and audience demographics. Although the potential of this R&D project made this opportunity very clear.

By delivering immersive audio and video, it's clear to see that audiences would be willing to pay for remote live streamed interactive events. Whether it be an unwillingness or inability to travel, or to take advantage of being immersed in the event from 'the best seats in the house'. It could be the ability to select different camera (visual) and sound (audio) experiences from different locations within the live performance. The highly personalised, and even 'backstage' experience that can be offered will surely attract a new and engaged audience.

Figure 27 : UC2 Architecture



Audiences of the Future (3rd Person Professional Perspective) - Nick Young

The virtual festival accessed through the VR headsets and headphones was good fun and was really well received, based on when I was watching the audience. A number of people had never had a go on a headset before, so the sense of novelty was enhanced by that. But when speaking to audience members, a number remarked on the quality of sound experience and sense of 'liveness'. There were conversations about the set up of the virtual screens in the virtual room, and whether they could be placed in a way that gave more of an immersive experience than the crescent formation. However, this was always agreed to be explored more during the development of the project post-R&D phase, and did not lie immediately in the current project scope. Interestingly, this resonated with the artists feedback of curation of visual feeds to create a more familiar and immersive environment.

The Founders Room setup gave a real sense of the potential of remote venues, where people can come together for the shared audience experience when unable to attend the actual event in person (something that is commonplace in sport, but curiously rare in arts & culture). One interesting observation of UC2 - and this may be subjective - is that by having all of the performers watched on a screen, rather than some live and some remote, there is a greater sense of equality of status of the performers, unlike at times in UC3 where there could be a strange cognitive dissonance around who the 'lead' performer was for that piece, the front person on the screen, or the backup singers on stage.

The set-up had progressed from the audio broadcasting in stereo to across 8 channels through the CSP between November and March. The audio was a crisp, clear, and dynamic immersive experience. (I think) I noticed the difference when I was in the room alone during tech runs. However, when the audience was in the room, the end-on set up of the visuals meant that trying to see what was going on distracted and detracted from the fullness of the audio experience. Spatial set-up and dynamics for artists and audience were a recurring theme to be explored in the commercialisation of the project.

An issue for consideration around the remote audience experience is the resolution of images on-screen. The linear camera feeds were (as you would expect) sharper and clearer than the onstage camera phone feeds due to the hardware being used. Whilst it wasn't a major issue, and one adjusted quickly there was still a lack of cohesion across the video feeds sometimes that wasn't experienced across audio. The continual speed of smartphone camera quality iteration will greatly enhance this capability.

There is a real potential of this to help create a better cultural democracy where money, health, location, and other currently preventative issues that stop all people having access to great art, are dissipated. There is also potential in areas such as education in allowing greater numbers of people to access these works and experiences directly, and to form their own relationships with the work. Audience feedback, as well as artist's input will also inform the development of the design and implementation. It will be interesting to see how UC2 informs, interacts, and shapes UC1 as it becomes more mainstream.

Audio Review of UC2

'The Founders Room setup gave a real sense of the potential of remote venues, where people can come together for the shared audience experience whilst not being able to attend the actual event in person (something that is commonplace in sport but curiously rare in arts & culture).'

This is a subject that has come up a lot during the course of this project. It is well documented through various organisations and publications that the UK Music industry is responsible for putting over 500K tonnes of carbon into the atmosphere every year, so clearly something has to change.

As the comment suggests, people go to the pub and other public spaces to watch sport, so why not a concert? We all know there is nothing like being in a large crowd watching your favourite band and the feeling of being part of something that is only happening there and then. However, if we are to play our part in helping to halt climate change, we need to seriously cut back on the number of large-scale arena/stadium shows that happen. So, for example, instead of a band playing 20 arena shows in one tour and trucking tonnes of equipment from venue to venue, not to mention all the cars that drive to those venues, why not cut the tour in (at least) half and live stream the 10 shows to people in local areas. Live streams could be held in pubs, local cinemas and theatres, on village greens and parks and of course into peoples' homes. This would still bring people together for a shared experience and a sense of 'being there', as well as provide revenue for local areas and employ local AV companies to set up the video screens and immersive audio systems.

However, to create that sense of being there, it is important to give the audience an immersive experience. I believe we're well on the way to achieving that with the audio that was produced for UC2. Through the use of Dolby Atmos processing, we were able to produce a number of immersive mixes, from the 3D studio housed at Metropolis studios, by taking the audio that was being produced by the musicians in the three remote venues and then live streaming it out in Binaural for those watching the festival on mobile devices and using headphones, and a 7:1 surround mix for those listening on the d&b audiotechnik speaker system in the Founders Room in Brighton Dome.

Hearing is three dimensional. The human ear consumes the sounds of the natural environment in three dimensions. Our actions and emotions are triggered by the sounds we hear all around us. By streaming immersive audio to people, then, whether they're listening to a binaural mix on headphones, a large scale spatial audio system like d&b's Soundscape, a 5 or 7:1 mix in their homes or even stereo (a Dolby Atmos version of stereo is a much better representation over conventional stereo because of the way the Dolby processor handles the out-of-phase information and gives the mix much more space and nuance), we are able to create a sense of space, and of being at a live gig with the sounds of that live gig all round you. Spatial audio creates a much more emotive experience.

There is still significant development work to be done. It is not currently possible to stream true 'Object Based Audio' through a web browser. Object based audio differs from channel based audio (which assumes a specific arrangement of speakers – 5:1/7:1 - and then leaves it to the mixer to figure out which ones should be used to make a sound "appear" in a certain

place) by taking those audio objects (instruments, vocals an FX), along with the objects 3D positional metadata, and creates a spatial audio experience regardless of the loudspeaker arrangement.

The next phase of this project will see us working with live and broadcast spatial audio specialists to develop ways to further enhance the audio experience for those watching on mobile devices, live, in venue, experiences and developing 5G equipped immersive studios for live broadcast.

Figure 28: The Sonosphere Immersive Audio Studio at Metropolis Studios.

6. UC3 - Beta Testing Completed

6.1. UC3 Video Beta Testing

6.1.1. UC3 Beta prototype app and front end description (MATI & O2 labs)

The CSP was used to provide both a local stream of the linear cameras with embedded multichannel audio. This feed was used to provide content to the remote viewing areas such as the Founder Rooms. The initial scope of the project was to provide the remote locations with stereo audio. During the trials, 7.1 audio was tested and was planned to be provided during the showcase. The UC3 feed was encoded via Open Broadcaster Software (OBS) which proved to be a weak link in the streaming of UC3.

Figure 29: UC3 Video Stream Station & Data

At two points in time the audio of UC3 was stuttering for no immediately apparent reason. Rebooting the VM, resetting it or creating a new streaming profile did not clear the issue. The solution to fixing this was restarting the OBS (Open Broadcaster Software) which resolved the issue during the project.

In the hours prior to the start of the final showcase, two channels of the 7.1 audio were mixed into other channels. Resetting the VM's streaming configuration did not fix the issue.

It is speculated that OBS was the potential cause, but there was not enough time to investigate the reason behind this during the event itself. During the 5 tracks played during

the event, both the VM and end-user applications were running fine, but there was not enough time to test the 7.1 setup.

The UC3 stream was also pushed with binaural audio to the cloud infrastructure where it was transcoded to multiple renditions, segmented and streamed out to the end users using the O2 application.

6.1.2. Video (description and test/feature lists (tested or to be tested)

Table 11: UC3 Video test list

UC2 Video test ID	Test description	Target KPI	Measurements (if already tested)	Comments
UC3VT1	UC3 audio channels	2 channels	5 channels	
UC3VT2	UC3 latency	40 seconds via cloud	7 seconds via local VM	

6.1.3. UC3 Output Streams and Live Audience 'In Venue' Experience

Set Design & Staging

The set design for both the Brighton Concert Hall & the O2 Blueroom proved effective in its ability to show the remote collaborating artists playing on stage, whilst at the same time not being the standard rectangle presentation form that most concerts use for live camera feeds and visuals. Each venue had five separate projection surfaces to allow up to five different musicians to be seen playing with the in-venue artist at any one time. When all of the musicians could be seen and heard playing together, a very convincing, entertaining and exciting experience was created for the audience.

As the two venues were very different in their size, floor plan and site lines, the approach to the design needed to be flexible enough to work well with the other elements of the show, whilst still feeling like the same world. All of the set design projection surfaces were surrounding the musicians and above them on stage. In Brighton Concert Hall, there were projection surfaces hung above the band, on both sides of the band, on stage and to the very far left & right of the stage on the Organ Screens, that framed the stage with the largest projection areas. In the O2 Blueroom there was a projection surface above the band, on

both sides of the band, just at the edge of the stage at the same height as the band, and two larger projection surfaces just above both to the left and right.

This presentation led to a feeling that you were watching a band play together in front of you, whether virtually or in person.

The original plan was to cover up the large LED Wall at the O2 Blueroom, but a need to present a remote viewing experience when no one was playing on stage at the O2, developed. We decided to use the LED Wall, with a triangle mask, for visual content behind the musicians when they were playing live which was then switched over to a standard 16:9 rectangle when it was needed to be used as a viewing room experience for watching the broadcast live stream that audiences at home would be watching.

There was a collaborative approach taken between the MakeAmplify VJ/Visuals team and the immersive audio team for laying out where the different players from each venue were located on screen, so that the immersive audio team would be able to place the audio from the player in their respective location in the immersive sound system. An example of this at the Brighton Concert Hall was the placing of the remote guitar player at the O2 Blueroom on a projected stage design surface on the opposite side of the stage to the in-venue guitar player, in order to ensure each guitar could distinctly be heard and seen in different spaces. One of the main requests from the immersive audio team was to have the singer on the centre projection surface, so as to ensure the voice was coming from the centre of the stage, with the bassist on the lowest and most central projection surfaces, aligning with the visual programming of the show.One of the key realisations during the live event was that most people, when watching a band play in front of them, do not expect the band members to move position during the show. This secured confidence in our decisions to have the same players appearing on the same projection surfaces throughout the show and that this did not seem out of place or repetitive.

Another challenge that the stage design helped to alleviate was hiding the inherent video latency of the performers by separating them physically far enough from each other that viewers could not look at both at the same time. The best example of this was used in the O2 Blueroom, where the live camera feed of the drummer in Brighton was on the stage furthest left design surface & the percussionist at Metropolis Studios was on the stage furthest right design surface. These positions switched throughout the show, but the artists being presented on opposite sides to each other remained constant.

The LED Bars that were mounted to the projection surfaces at the Brighton Concert Hall helped to bring even more life and colour to the set design. When there were artists performing on the Brighton stage with only a few other musicians, or by themselves, the LED Bars were used to create a more dynamic visual performance.

The LED Pixel Mapping of the columns that were in the seating area of the Brighton Concert Hall created an immersive visual experience directly linked to the on-stage performance and visual presentation. This meant wherever you were watching from, there was a more vivid connection to the show on stage.

Projection mapping the ceiling of the Brighton Concert Hall proved to be a very interesting and entertaining element of the show. There was a combination of presenting the same content that was on stage simultaneously, as well as other content that complimented the stage performance.

The main creative challenge & brief to MakeAmplify for this project was to create an immersive visual experience which would match the ambition & concept of the 5G Festival goals - that being to connect three different venues and 21 musicians simultaneously. We focussed attention on the beautiful architectural features of the Brighton Dome which surround you in the space by lighting the columns using LED Bars, projection mapping the ceiling and projecting onto the organ screens, as well as the overall concept of the set design for the show. The visual experience within the venue complimented the incredible immersive audio experience that was achieved at the showcase, and created an event that was the first of its kind in many ways.

In the January Trials, we tried to use the phones in landscape rather than portrait mode and this proved to be much more effective for all the video teams and didn't have much, if any, effect on the musicians using the phones for UC1 & UC2 experiences.

One of the main challenges of the showcase was that there was no phone used for the two main vocal artists at the O2 Blueroom, Natalie and Lola; they were too far down stage and a phone could not be set up in front of them as it would have blocked the audience's view. This meant that the team at Brighton Concert Hall were solely reliant on using the ATEM linear camera mix for the lead singer, which always had slightly more latency than the camera phones and was meant to be shooting the entire show for the 'at home' audience, not just the lead singer. As we were all on comms for the show conversations with Steve Machin at the O2 Blueroom, this ensured we did get the lead vocal artist most of the time with the shot we needed, but this could have been avoided if there was a dedicated camera phone for these artists.

UC3 Projection / Stage Screens Output

The CSP worked incredibly well and was very solid throughout the show and main rehearsals. Luke at Matavision was able to take most of the feedback from the trials, especially the January trials, to ensure that implementation for the showcase took most of what was most necessary to run a live visual experience into account.

- When a camera dropped out, it would come back up in the same location on screen in the web browser as soon as it was working again
- The bit rate selected would stay the same as the last time it was set when refreshed
- Four different camera feeds were enabled on each CSP web browser window
- A black background was used instead of white when the camera feed dropped out to minimise visual difference/shock

What could be improved in the CSP for commercial usage:

- The selection tool that popped out from the left hand side and needed to be closed was not very useful during the show, where the different cameras needed to be selected.
- It would be good to have the list on top at all times so that the user would know that certain camera feeds had dropped out and were unavailable.
- It would be useful to have keyboard shortcuts for the different camera feeds or a drag and drop feature for each of the 4 spaces independently
- Only one CSP Web Browser could be used on one computer; when 2 were used, it would force the computer to restart. This means, if trying to do a show with more than 4 different cameras/musicians, you would need a computer for all 4 remote artists.
- A very high spec computer was necessary to run the CSP Web Browser without compromising the quality.
- A very high spec computer was necessary to ingest into the CSP Web Browser.
- Syphon, Spout or NDI would need to be added to each camera feed, so that there would be no need to use a capture card and the camera feeds could be directly used within the VJ/Visuals Software.

Capture cards proved to be the aspect of the show which were the least reliable. During the January Trials, four capture cards were connected to a specific MacBook Pro computer, all running simultaneously without an issue. During the showcase, they could not be run consistently without one freezing up and needing to be unplugged and plugged back in. We tried many different capture cards and combinations, but could not get any of them to work consistently. Based on this, a key recommendation for future events would be to get each camera feed from the CSP to integrate Syphon or Spout technology. This would mean that capturing the web browser from one computer to another would be unnecessary. In terms of turning this into a commercially viable application, the capture card method would not be a good enough solution.

The lighting for each of the artists was improved greatly for the showcase and they all looked much better on both of the phone cameras and the linear cameras. There was still an obvious quality difference between the camera phones and the linear cameras.

There were at least two camera operators on the linear cameras in each venue which had a very positive effect on the quality and dynamic of the camera feeds being displayed on the projection screens.

Presentation latency for the in-venue video screens was an area that required management across each of the two venues, with projections from the 3 venues. The core challenge was around the latency from lens to screen via the CSP. A significant amount of work and testing was undergone in order to measure and optimise the equipment used for capture and transport of the linear video from the UC3 cameras. The projectors at each venue, and the LED screen at The O2 Blueroom, added an additional and significant amount of latency to the overall performance of the system. In tests, the LED screen at The O2 Blueroom added 230ms to the total latency within the local loop at the venue;the total latency for the local loop was 310ms so the screen was a major latency expense. For future commercial

applications, utilising screens / projection / display devices with consistent and low latency would be a part of the scoping for deployment.

Main recommendations for the next development of this project:

- Making use of the rear phone cameras for the UC3/showcase, so that the image resolution could be much higher quality, including manual features of camera control and use of a wider lens.
- Integration of Syphon, Spout or NDI technology into the CSP so no capture cards are necessary to work with Visual/VJ Software.
- A much more significant emphasis on the bid writing, planning, production, creative development of the show with the Musical Director/other creatives & an allocated budget for the visual presentation/performance of the project.

6.2. UC3 Audio Beta Testing

6.2.1. Audio (description and test/feature lists (tested or to be tested)

6.2.1.1 Network considerations affecting audio

Figure 30: Network considerations affecting audio

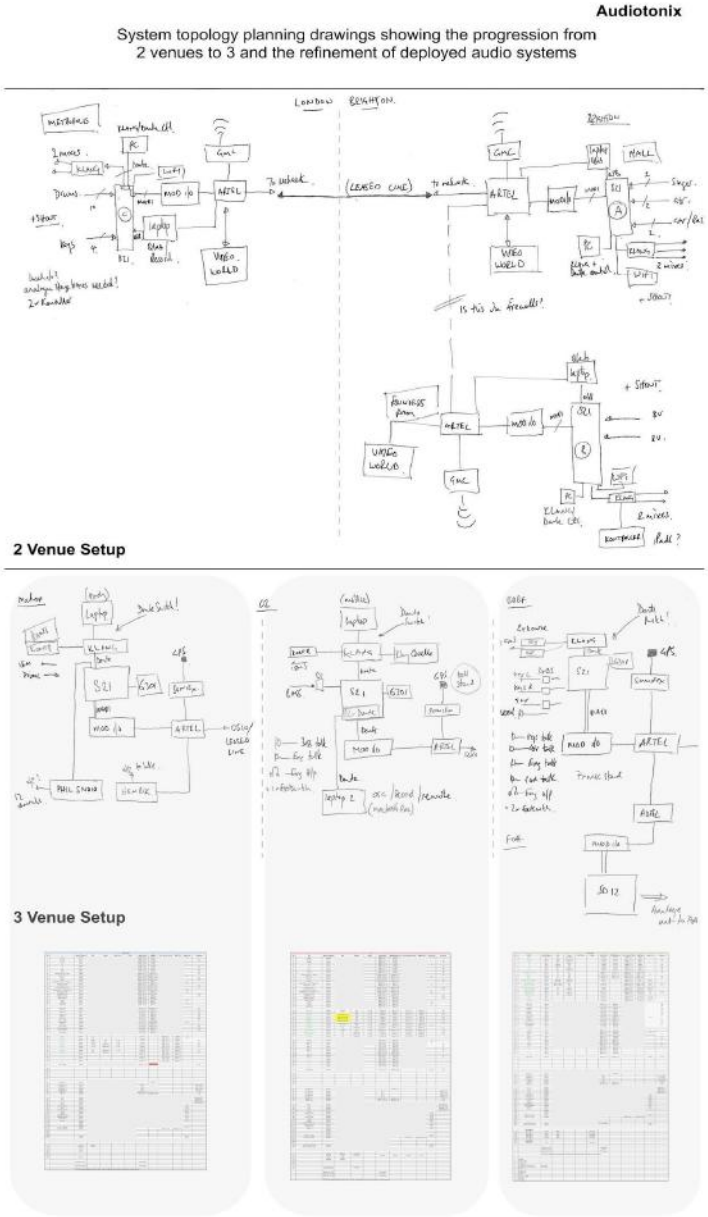


Diagram showing complexities of 3 venue and channel planning - detailed view in appendix

Network considerations affecting audio

A smaller desktop switch (Cisco ISR 1100) was purchased and planned to replace the mini PC terminating the GRE tunnel and run the PIM-SM, as it was thought that the mini PC may not be sufficient for the larger number of audio streams required for the showcase because the CPU may have been blocking high throughput packets. This was not load tested, and PTP was not tested over the 5G tunnel as anticipated (only multicast audio). It is suggested that this is put forward for future project testing.

In November trials, there was an issue with sync drift between audio and video for the UC3 LB into Founders Room and one potential problem was highlighted,although it is thought that this drift was compounded by several different factors, and it was not an issue in the Showcase, as an embed method was used to distribute the streams)

UC3 linear cameras were connected directly through HDMI to laptops that were running the CSP front-end software. These laptops were wired to the testbed. The wired infrastructure was capable of carrying multiple GBps traffic, so no bottlenecks were to be expected from the network point of view. However, the computation capabilities of those laptops is a bottleneck, as reported in section 2.2 [MS6b].

It was reported by Mativison that during the showcase event, there was no lag on laptop based streams. For example, UC2 was receiving 9 streams and was at 40% utilisation. The phones, on the other hand, when multiple high bitrate watchers were connected, this would cause them to run slowly. To alleviate this issue, we switched the default settings for UC1 and UC2 to a lower bitrate.'

It was noted in MS6 that proper traffic prioritisation should be used and potentially throttle some traffic if required, particularly since the Comms System would be utilising the testbed network.

For the showcase, Differentiated Services Code Point (DSCP) was enabled on Cisco for prioritisation (particularly for PTP/Audio). Throttling was not enforced on other traffic as video was much lower resolution than originally thought.

PTP was given highest priority, followed by audio RTP, followed by all other traffic using inherent DSCP tags in Calrec AoIP streams and PTP from the Sonifex. This was because…

Digital Clocking & Audio Network

A decision whether to run the audio network at the increased sample rate of 96kHz was made after considering the complexities of the showcase set up.

For the final showcase, given the number of musicians and the work carried out to mitigate any network stability risks, we ran the entire audio system at 48kHz. While elements of the system could have been run at 96kHz, it would have added little benefit within the scope of the project. In addition, we had previously proved that 96kHz was possible and documented the advantages it might offer.

Audio Network Bandwidth

The final stream patch for the showcase consisted of up to 6 streams being transmitted, with between 8 and 10 streams being received in each venue. The varying streams per venue were a result of the distribution of musicians; adrummer generates many more channels of audio than a guitarist and, as such, the venue hosting the drummer places much more audio onto the network. In total, there were 35 8-channel stream patches (equivalent to 280 channels of audio).

From a bandwidth point of view, a single 8ch stream at the 125us packet time used 14Mbps of bandwidth. The Brighton to Metropolis link peaked at approximately 214Mbps with average figures on the other inter-venue links between 90Mbps and 130Mbps.

Bandwidth was managed using DSCP tags on PTP and Audio RTP packets to prioritise them over other traffic. This was using class and policy maps (on the Cisco switches) to classify and apply policies to the traffic on ingress and egress of the inter-switch links.

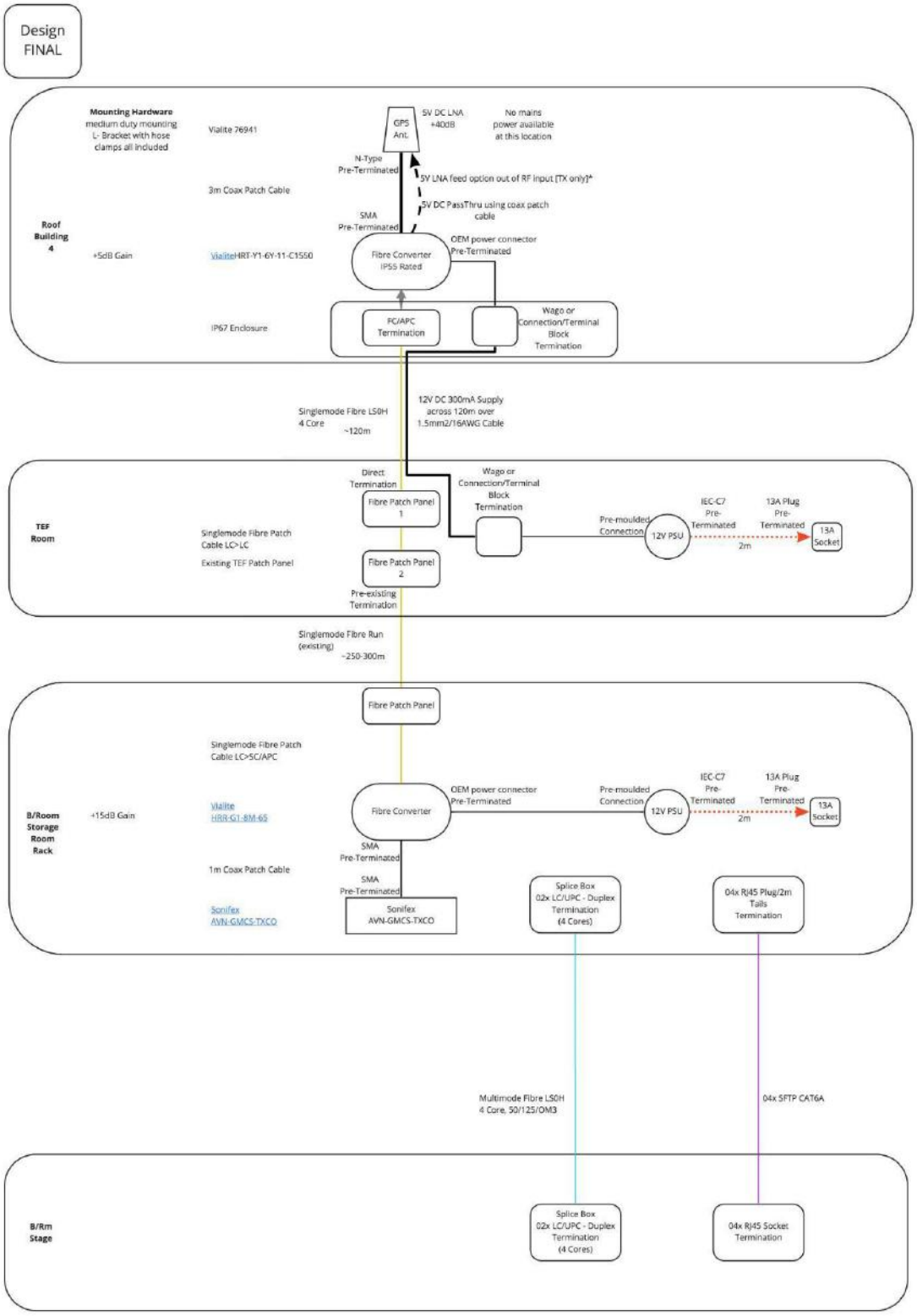
Final GPS/PTP Installation - O2

Whilst following this installation to conclusion, it was noted that the extra time, effort and resources necessary to complete and sign off this installation were needed, especially when compared to Brighton Dome and Metropolis. Many email chains, several back and forth decisions and a plethora of phone calls were required across a large group of people from several different companies, to install what is, on the face of it, a fairly simple design. A compilation of design documents, route planning and RAMS required to commission are included in the appendices.

The reason for this additional resource was the complex multi-organisational structure of the building; whilst the Blueroom venue itself comes under the banner of O2, the building belongs to an overarching parent company that is required to operate legally as a separate entity, and the complex itself is home to many other individual chain or independent companies as tenants. This meant that strict rules and regulations were necessary, and has to be followed explicitly to maintain the safety and integrity of the compound; it took time for all of the decisions to be put into place because of the very size of the team needed to implement these processes.

It is thought that once 5G infrastructure, and the relevant features of the technology, are delivered and more widely adopted, then the ad hoc nature of these types of events will be much more easily achieved. This is because the equipment required will utilise the common network features that are installed as part of the 5G backbone nationwide, and configured explicitly for the needs of the event via software. Therefore, these types of installation will not be required and the commissioning of a system should take a matter of days rather than weeks/months to complete.

Figure 31: Final GPS and Cable Infrastructure for O2



Playback & Click

During the June trials it was decided to test the effect of the location of the playback and click system in relation to the musicians, and investigate where the most and least optimum location would be.

Following testing during trials, it was found that the location of the playback and click system for the showcase had to be in the same venue as the drummer (the drummer is essentially the musical time-keeper or metronome). For the showcase, there were two timekeeping instruments and these were in different locations: the drummer was in Brighton and percussionist in Metropolis. We decided to keep the click in Brighton for the show. For one of the rehearsal days Kojo, the Music Director, was located in the O2 Blueroom and was able to run the click from there.

Across the trials and showcase, the only person to voice any issues with the click timing was Kojo, the MD. This wasn't a surprise, as his job was essentially to listen critically,without an instrument of his own, which masks any slight timing differences. He was therefore able to pick up on the slightly different arrival times of drums and percussion based on the time it takes for the click to travel to the remote venue and then the time for that audio to return. The extent to which Kojo noticed the difference in this timing was also based on the mode of latency the audio network was running it at; this issue will subsides when network latency is reduced.

Back in the earlier trials, where we tested locking the click to time of day for synchronised delivery to the musicians, the gain from this approach was outweighed by increased complexity. As this technology system moves forwards, there is a case to research the use of edge computing on the network for click delivery from a central network point out to each location;how that delivery is synchronised would be interesting to explore further.

It has been proven that where the latency is low enough, click can be used, particularly in instances where the musicians didn't notice, and the audience certainly weren't affected by the timing of the click.

Network latencies prohibit this system from being in any other venue; in any future commercial system or platform, any requirement for a click based timestamp should take into account latencies between sites and how this affects the ability for multiple musicians to play together in time.

In a collaborative festival scenario, for example, it may be necessary to have playback systems existing in all venues to take into account the fact that there may be more than one drummer/percussionist collaborating in the various setups.

6.2.1.2 Video/CSP considerations affecting audio

After the November trials (see 6.2.1.1) Mativision commented that the CSP was using a constant bitrate with bitrate switching based on network conditions. They reported that a fixed bitrate with no leeway produced an unstable environment when multiple peers connected to one device. This resulted in a fixed bitrate selection being implemented in the CSP interface. There is a potential that this may have added to the aforementioned issues mentioned in 6.2.1.1 (relating to drift).

November trials resulted in a recommendation to test the quality and latency offset delay in the viewing room monitor, which is required to offer perfect pictures and stereo sound as set by the CSP.

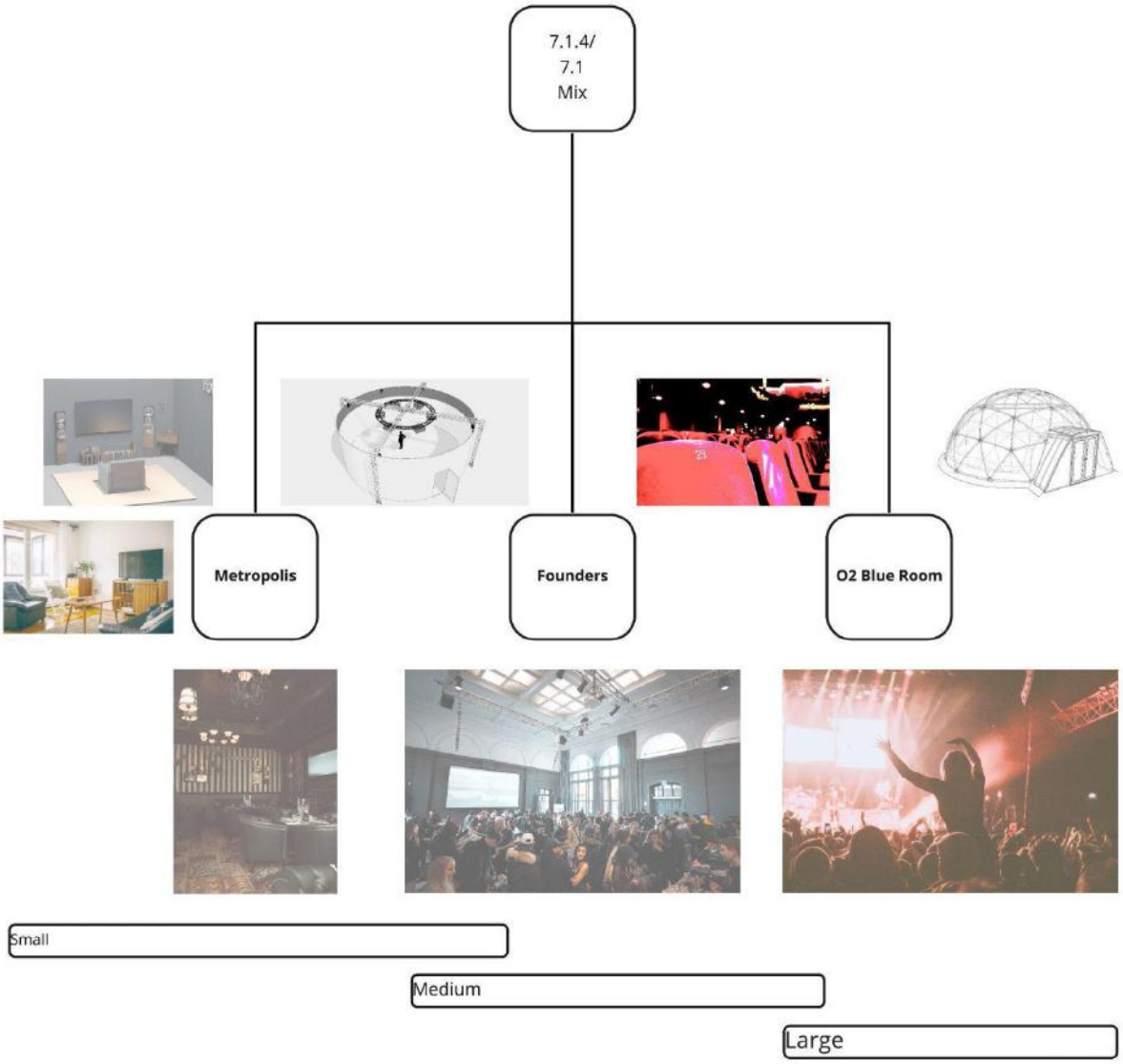
This was consequently achieved in the January trials and showcase by embedding the audio and applying sync delay directly, therefore negating any drift within the delivery system. The stereo feed was also increased to an 8 channel 7.1 embed.

Whilst the CSP provided a way to view all of the feeds from venues in a very efficient manner, considering the distances and technologies involved, there was no way to view the mixed visuals to the same degree. This was commented on at the time and it was noted that these visuals could be brought back into the CSP and offered as a selection within the interface. This, however, would likely still have had some issues as the individual feeds to the visual mix were also delayed to enable sync - adding to the overall latency before even hitting the CSP.

6.2.1.3 In Venue Remote Audience Experiences

The design factors surrounding the UC3 Remote Venues differed from the traditional stereo, or even mono, design considerations usually utilised for live venues. In theory, however, the similarities would be the decisions necessary to accommodate the wide variety of venues - one size does not usually fit all.

Figure 32: Types and sizes of Venue



This can be seen in the three, very different, venues in the project. Detailed below are some of the issues encountered and design considerations for each, particularly relating to how these considerations could potentially be made into a more homogenous approach in future projects, or in a final production environment.

The Founders Room would be the more typical live venue/viewing room- the O2 a hybrid live act/viewing venue with Studio A representing the crossover between home theatre, small cinema and small live venue/bar environments.

Founders, O2 and Metropolis Studio A

The concept of 7.1.4 delivery and effects on the mix were tested through the Studio A system, which utilised more typical studio monitor type speakers, as this could be directly connected to the render output and serve as a control/QC point.

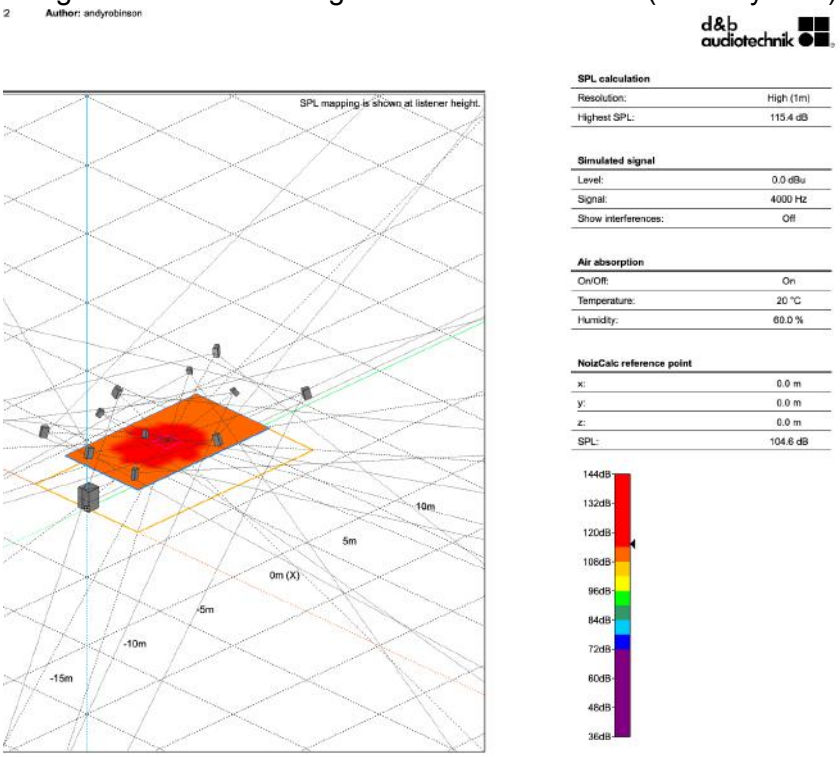
The design aesthetics for the Founders Room viewing experience were put together to allow the audience to be immersed in the sound from the remote venues and feel like they were there or ‘taken away to another space’.

The decision to mix within the Dolby Atmos ecosystem meant that there were several options for the output format, including 7.1.4 (surround format with added height channels) and 7.1 (more traditional surround format with all speakers in a horizontal plane).

As this was a staged or staggered development process, it was decided to deliver 7.1, which was the compromise between spatial resolution and delivery capabilities under the remit of web browser/app front end (most stable A/V sync vs channel count).

d&b Audiotechnik loudspeakers (Compact PA Type) were placed according to Dolby recommendations for 7.1 (see appendix) and they were fed from a workstation receiving the video & 8 channel audio feeds via web browser, routed through a DiGiCo SD12 live console.

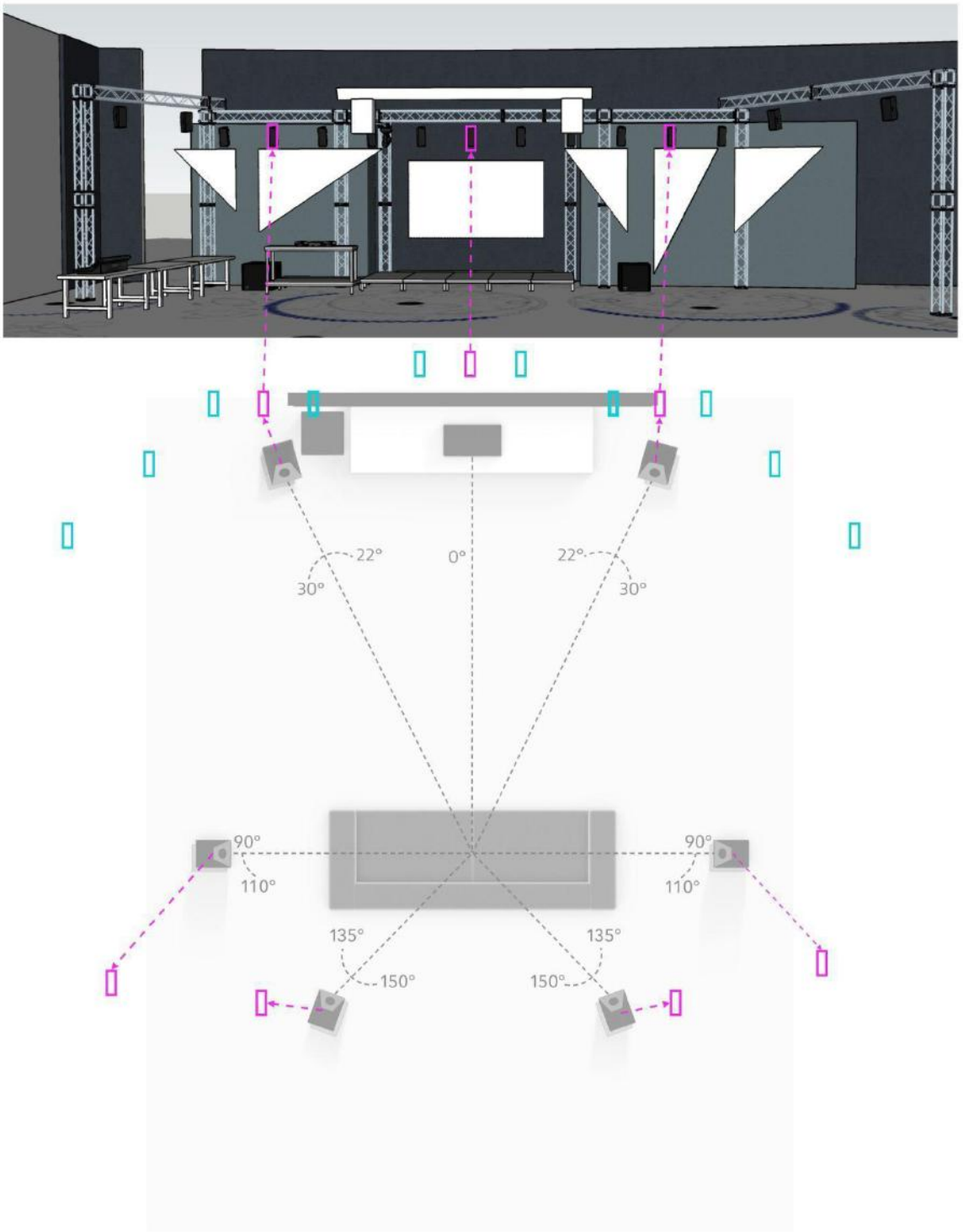
Figure 33: SPL Coverage Plot Founders Room (7.1.4 System)



Given that the venue was part of the ‘In Venue Live Audience Experience’, the system in the O2 Blue Room was a fully immersive d&b Soundscape system (similar to that of the Concert Hall, with a layout optimised to the O2 venue) enabling live, object based mixing from the DiGiCo Q338 FoH live console for the collaborative parts of the scheduling.

To account for the ‘hybrid festival’ nature of the UC3 delivery, in addition to the d&b Soundscape live elements there were moments where the streamed 7.1 mix (UC3 LB or Linear Broadcast) was scheduled to be delivered. As such,the 7 Dolby loudspeaker elements were placed within the d&b Soundscape loudspeaker system as appropriate, using the d&b Soundscape render engine to enable the correct angles between Dolby loudspeaker sources.

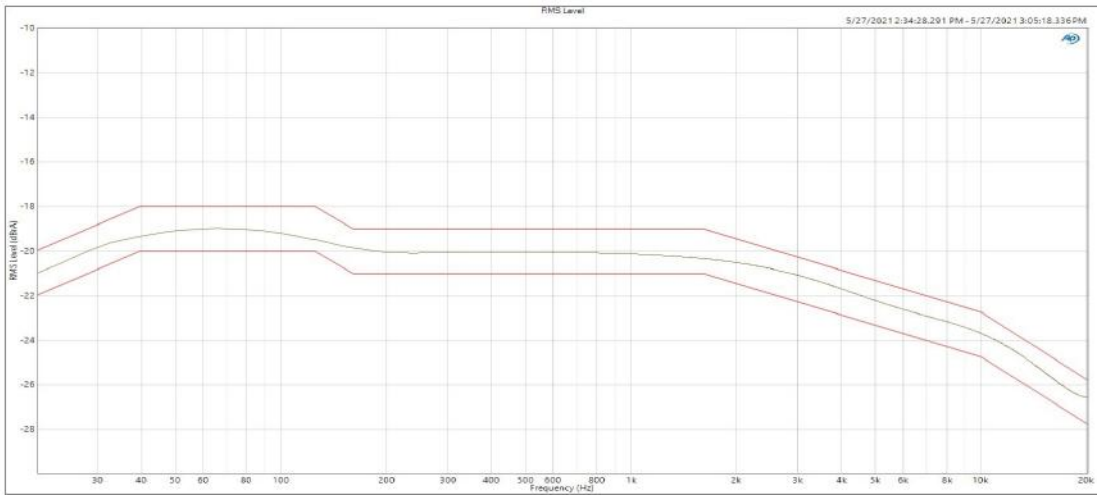
Figure 34 : Dolby 7.1 Layout to Soundscape Mapping



Set Up and Calibration

Studio A
This room was mainly set up for demonstrations during the showcase day; here, however, we could also measure the direct impact of all mix outputs from stereo through 7.1 to 7.1.4. This was then used as a QC point in the chain, where all the streams could be accessed via workstations and monitored as the performances were happening.

Figure 35: Dolby Target Curve Response



The calibration was mainly timing and level based (although this was also fairly minimal as the speakers were able to be set up fairly close to the ‘ideal’) with minor EQ changes to match speakers more closely. This was relatively time efficient when performed by a very experienced engineer and the mixes translated well, even with a larger and livelier (more reflective)room.

Results - Studio A

Switching between the various speaker delivery formats (Rendered Stereo, 7.1, 7.1.4) left no real doubt as to the effectiveness of the immersive formats over the traditional ‘frontal’ based systems. Whilst the render processor gave a much more satisfying stereo image and depth, and the 7.1 an expanded sense of width and depth, the 7.1.4 was the only one that managed to convey the sense of environment and the feeling of being in another room effectively. We considered this to be mainly due to the fact that the additional height channels helped to ‘glue’ the sound cues and cement the illusion that these cues were coming from the same space. Without these, the human brain can get confused, as it is trying to take directions from an external room (conveyed over the speakers) and the real room interactions (echoes and reflections within the actual room the system resides in).

Further subjective listening tests are required to cement these theories and findings where A/B preference comparisons are made (similar to opticians tests) where the comparisons are Stereo/7.1; Stereo/7.1.4; 7.1/7.1.4 to get a thorough data set and confirm these findings.

Founders
This system was calibrated in compliance with Dolby's recommendations for 7.1 systems with bass management. As above, we utilised Smaart software to meet both the frequency response (see above image) and loudness requirements to accurately reproduce the 7.1 mix, utilising the console delay and EQ to conduct the calibration. This was undertaken in order to test the simplest and most accessible method available to represent a typical set up most within reach of the budget for these types of venues, and assess whether this would be enough to accurately present the mix.
As expected, this room required a little more in terms of both time and adjustments to calibrate, due to differences in positioning of equipment (due to room layout/shape/height, entrance/exit positions, position of other equipment/projectors etc). In addition, the surround speakers needed to be placed at a 90deg angle vs the 110 of Studio A - although this is within the Dolby delivery specifications. It was interesting to see whether this would also have an effect on translation within the context of an alternative setting.

Results - Founders room

The placement of the 7.1 configuration was relatively straightforward to implement within this space and was set up using speaker stands. If a 7.1.4 system were to have been used, it would have been necessary to deploy a trussing system, which would have added in a secondary skill set required (for building the truss and flying the speakers) and additional costs for the physical trussing itself.

To reduce costs in the future, typical system packages can be designed and built to do this as economically as possible. Further viability studies need to be conducted as to profitability when compared to ticket value and attendance capacity.

One issue encountered was that of the 90deg vs 110 deg comparisons mentioned above. Whilst this was within Dolby spec, it was found that there was a lack of "fullness" towards the rear section of the room (coverage of the audience space), which was eased by feeding a blend of this signal back to the rear speakers. The issue with this was that the spatial information started to become confused.Looking into the feasibility of object-based rendering of these signals may prove to be beneficial in the future. If the speakers had been able to have been placed at 110deg, this may have also helped to alleviate this somewhat, although the former would be a more reliable and flexible way to improve this situation, working across a wider range of environments.

This could also have been relieved by the use of height speakers, as these would help to cover the space more as a whole, and, for the reasons mentioned in the Studio A section above, either of these alone would not have solved the problem entirely.

Calibration via the console proved to be reasonably efficient and reliable, although it tooka little longer than Studio A (which is to be expected as the room is larger and has a much different acoustic property to the studio setting); these findings would have been the same for traditional frontal-based stereo systems.

This calibration was tweaked slightly (EQ adjustments and slight level readressments) as the performances happened, to allow for the usual audience and temperature variations. There was a slight adjustment necessary on the bass end which had been expected due to the room size. All of these adjustments would be similar to those made with traditional systems.

O2 Blueroom
The system was once again calibrated to the Dolby recommendations utilising the desk EQs / Delays on the 7.1 channels so that the Dolby content could be delivered while maintaining the d&b SoundScape setup simultaneously (the d&b SoundScape was calibrated independently for accurate spatial coverage within the room - as per Concert Hall).

The difficulty here was the shape of the room and how a 7.1 mix would translate into that space. There were multiple loudspeakers deployed by the SFL team within that system so that the d&b SoundScape could render the best spatial information. A 7.1 system would only reproduce 7 main speaker positions within that space and, therefore, would leave some gaps in the coverage. It was decided to test the effect of this VS utilising the d&b SoundScape to effectively ‘spread’ (or diverge) the spatial information across the rest of the speaker system, to see if this was necessary, or whether a direct 1:1 speaker bussing would be suffice (simpler in terms of setup and configuration).

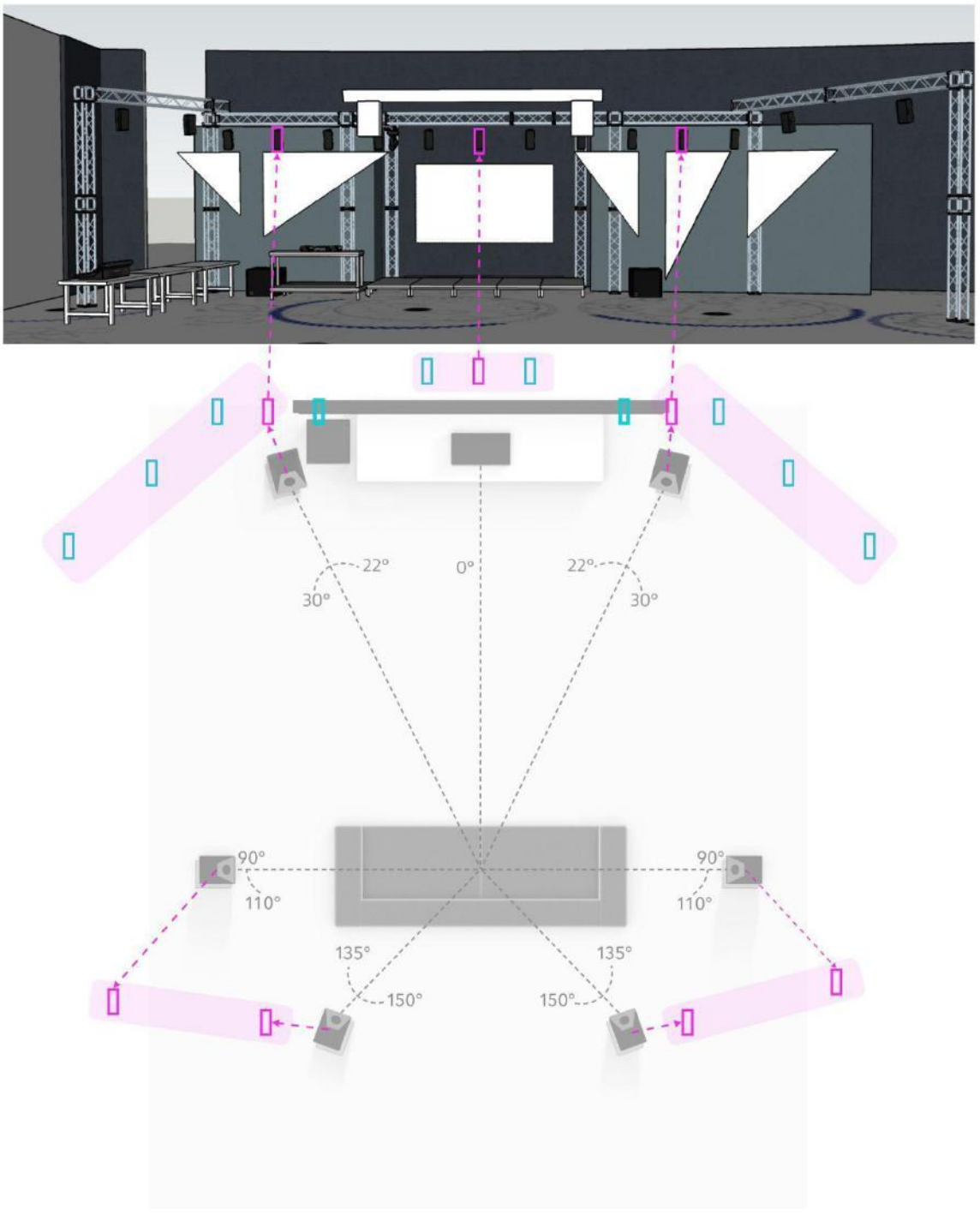
Results - O2 Blue Room

The configuration of the 7 Dolby loudspeaker elements within d&b Soundscape and the reference curve implementation again proved to be relatively straightforward and not time consuming, as with the Founders Room. As the venue already had to utilise a trussing system (for sound and lighting), implementing this did not have a further impact on cost and only extended the time taken to set up the system as a whole slightly.

The shape of this room obviously had the most impact of the three and therefore the d&b Soundscape played a large part in being able to deliver the 7.1 mix more accurately throughout the space to more evenly distribute the signals so that gaps in the coverage were minimised.

Unfortunately, the end result was unable to be tested with a full audience in the showcase, but the initial tests proved promising and helped to ease those pockets of coverage gaps, and this does highlight the differences in the types/sizes of venues.

Figure 36 : Dolby 7.1 Layout to Soundscape Divergence (Spread)



Results Summary - All

It was hoped that more definitive conclusions had been reached and that we could have gained more ground in the gathering of data with regards to these various setups. However, due to the over-delivery in other areas, and the change in tack on the approach, this section had to scale back to allow for the resources to be spread more effectively to produce the Showcase event. As it stands, further research, development of ideas and effective feedback planning is required to push this forward to a pre-commercial stage or TRL 7 (currently TRL 3-5).

Although there was good ground made with regards to discovering the complexities of interfacing all of these technologies and vastly varied venues, with useful feedback gained, more intensive and in-depth listening tests are required in this area to fully assess the effects of this type of rendering on the mix accuracy and spatial quality, and whether a future pure object based translation would alleviate any issues presented; as the O2 venue represented one of the most difficult or tricky scenarios, it would be well worth testing and perfecting techniques in these types of rooms, the results of which would waterfall down to the less trickier rooms ,but enhance the quality of the rendering in those environments.

One of the practical thoughts behind the 'viewing rooms', and for this service to be fed from a central hub or point, is to provide a method for a communal audience to experience a live event whilst reducing costs to the venue (enabling more of these types of event to happen and avoiding some of the prohibitive expense), whilst maintaining the look, feel and experience. For instance, a Soundscape system would probably be considered overkill for a smaller viewing room such as the Founders, especially when adding in set up and engineering costs. This also helps to promote a more local service ecosystem and cut down on some ecological costs, too.

The main questions here would be: does it feel more live than if I were to watch it on my device or at home? 'Is it accessible and within budget?'

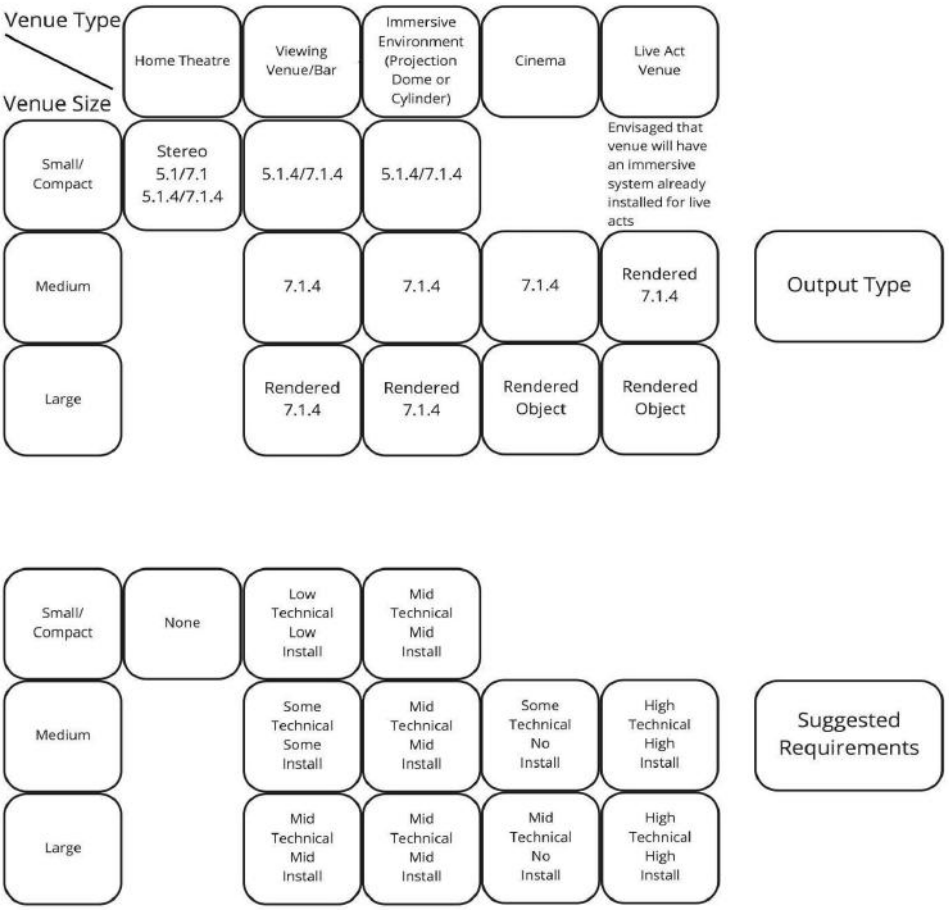
Whilst obviously taking longer than a traditional set up, the trade offs against the quality and audience's emotive connection to the music (audio presentation) within that space paid dividends. Event attendees commented:

> 'Audio was a crisp, clear, and dynamic immersive experience'
>
> 'Lack of cohesion across the video feeds sometimes that wasn't experienced across audio' - While performers were in different spaces, the spatial audio helped to put them into one context within the room.
> 'I think the showcase came across very close to my expectations from the initial concept from an audio and video perspective. I think the Founders room represented

a remote venue very well, with Metropolis Studio A feeling almost more like a high end home cinema'

It is clear that careful consideration is needed as to type and size of venue/viewing room and the translation of the mix to other systems, when also considering accessibility and budget.

Figure 37: Matrix showing suggested output per venue type/size and potential budgetary requirements



Technical Ability

Low = some ability and competence, no training - informational video
Some = competent and technical abilities, has some experience, competency training
Mid = competent and technical abilities, has good experience, full training
High = high competency and technical abilities, has good experience, enhanced training

Installation Requirements

Low = some ability and standard hardware (speaker stands etc)
Some = Competent/trained, potential rigging and truss
Mid = Fully competent/trained, has good experience, part of a package system/team
High = High competence/high level of training, has good experience, equipment part of a larger production/team

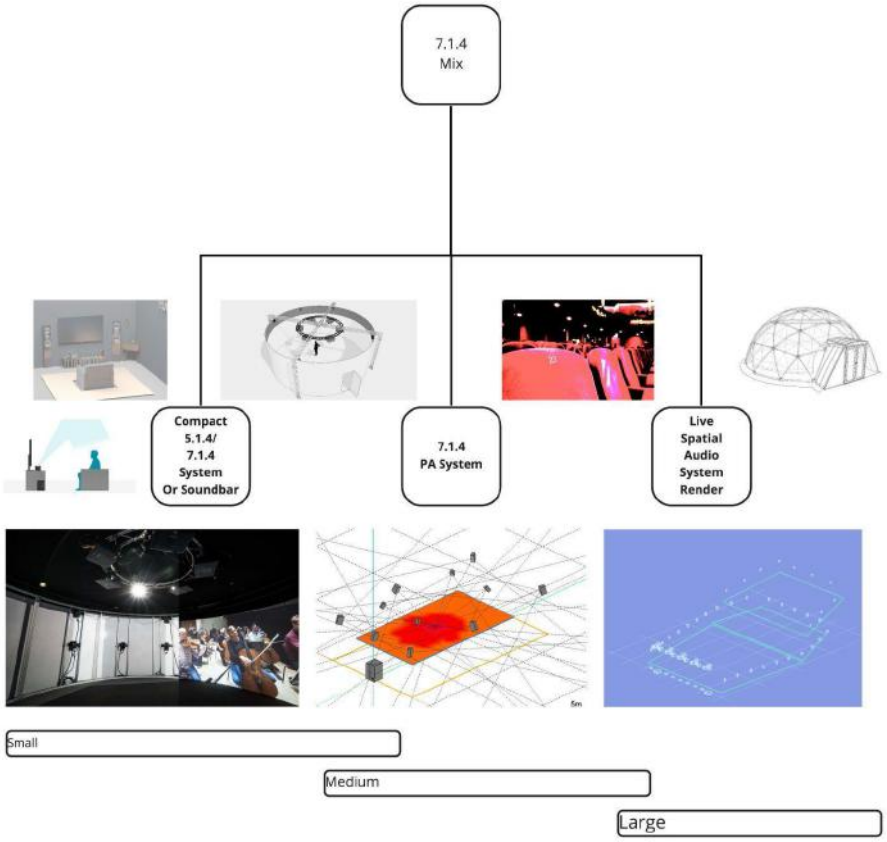
As room size increases, it is more difficult to achieve accurate locations of objects within a mix, as well as spatial cues from elements such as reverb or environmental acoustics/audiences without additional speakers to provide support and prevent a collapse of the soundfield within certain areas of the space, whilst also providing coverage for those areas.

The importance of the height channels when rendering alternate spaces, and the ability to deliver these additional channels to enable an all-encompassing environment, is paramount when trying to convey the essence of another venue and share a connected space.

The key question for future development is: how can we make best use of the space and deliver on intended audience expectations, whilst still maintaining integrity of the mix/engineers vision and enabling commercial viability in each scenario?

More research and subjective listening tests are required to fully answer this question. However with the existing technology, the below is a recommendation for typical systems based on findings of this project and feedback to date.

Figure 38: Typical Minimum Systems for Fully Immersive Audio



Based on the experience of the showcase, it is expected that a QC point similar to the setup in Studio A may be necessary for larger events to monitor all the various streams and final outputs, as in this type of scenario, it would be too much to expect the mix engineer to take on those duties. Smaller and single band events would probably find these duties residing with the studio engineer or spread across several small facilities.

Incomplete testing to take forward to possible future iterations

Unfortunately, there were a number of tests and feedback sessions planned that were not completed.It would be good to consider these in future assessments to provide better benchmarking of systems.

VR Microphone Comparison Recordings

These would be taken from the centre focus point (point at which calibration takes place) of each venue/system, utilising an immersive reference track as playback through the systems. These would then be assessed in two ways:

1. A spectral comparison using Smaart (or similar system) to analyse the differences of each room and system when compared to a studio environment.
2. In-studio listening - these recordings can then be listened to within the same studio environment they were created in and compared subjectively to one another (over speakers and via headphone binaural rendering).

Spatial Analysis techniques, using more recent technology, are now available and operate in the same way that Smaart does, but gives a real-time spatial comparison, making the process of comparison between venues and studio both quicker in addition to offering the ability to control this remotely and make/view real-time changes from the studio environment.

Audience/Ambience Capture

An immersive technique called a ‘Hamasaki Square’ was chosen, which utilised a sub-cardioid DPA4015 on each corner of a 2m square array in the centre of each audience area. These mics, when panned Left & Right, Front & Rear, provide a great perspective on the audience area in the given show venues, and are a tried and tested method for audience / space capture at live music events in traditional set ups.

The audience mics were placed on their own Control Group on the desk to allow fades and control over hitting the applause after a music number without getting too much in the way of PA colouration on the tail of the music.

Because of the super low latencies between venues and the immersive mix studio, there was not an issue with echo, as is often seen on live TV performances attempting a similar crossover (without the interactive part due to delays), for example, Last Night of the Proms on BBC TV.

'The audience mics worked brilliantly and provided a really immersive experience for those watching and listening remotely, both binaurally and in 7.1.' - Engineer Feedback

6.2.1.4 Own Device Remote Viewing Experiences

1st Order Ambisonics

An Ambix mix, as a live re-render from the Dolby RMU (Remote Mastering Unit), was used so that VR viewers of the broadcast output could enjoy immersive dynamic binaural audio with integrated head tracking.

Stereo (downmix)

This mix was made available for areas where simple 2 loudspeaker systems were being used for monitoring, such as studio control rooms and for people consuming the broadcast output on standard TVs.

Binaural (downmix)

This mix is likely the most utilised from a statistical point of view. 94% of all music consumption is from streaming providers (DSPs) delivering a static binaural mix via headphones, rather than standard stereo, provides the listener with a significant improvement of their experience. The ability of binaural audio to be delivered using the standard 2 channel format on mobile devices is one of the most accessible means for listeners, and the static binaural represents the tie-in with the Linear Broadcast as this is always anchored in a frontal direction.

Outputs delivered to the network as multichannel audio signals

7.1, 7.1.4, Ambix, Stereo & Binaural were all streamed simultaneously from the RMU to the wider audio network using Dante (locally) and converting to AES67 (wide area network) at the Calrec MOD-IO, catering for the diverse range of equipment accessing the streams.

6.2.1.5 Future UC3 Audio Delivery Pathway Concept

Over and above UC2 platform requirements (see Section 5.2.1.5), UC3 adds in additional artistic choices and mix aesthetics focussed more on a producer/engineer perspective.

UC3 adds potential for sources to be much more dynamic in terms of positioning/movement and therefore requires a different methodology and sync process/tracking ability to the visuals compared to UC2. This should be reflected in any future developments of a co-designed UX.

It is currently theoretically possible to deliver a full AC4 encoded stream (DVB standard) over browser based technologies (currently Microsoft Edge has the only official support so far, although Safari is enabled and will eventually announce officially).However, the live encoding side requires an overhaul and specific hardware/software development to take full advantage of the latest technologies and methods of output necessary for this type of robust commercial live streaming product.

Current products are either pre-encoded (non-live VOD), or a hybrid designed to shoehorn emerging standards into the delivery format of past technologies and, whilst in the emerging stages, this is a good way to prove concepts and encourage uptake/investment. It is a good time to re-develop these products from the ground up into a fully spatial/immersive ecosystem and leverage all the advantages this has to offer.

There are current developments that are in the pipeline, but are a way off and may still not satisfactorily provide for the requirements of this platform.

Ground-up integration of current and future technologies would allow for a concerted and joint effort to improve the ability and accessibility/integration/adoption of the platform, whilst increasing/spreading the financial risk/burden, which makes for a faster and more adoptive route to market, whilst still maintaining certain IP value and enabling futureproofing functionality.

5G enabled infrastructures would allow for the expanded bandwidth and speed required to deliver these kinds of streams and backup/failover solutions for mission critical applications of the UC3 nature in a highly and seamlessly scalable way.

6.2.1.6 Metadata and Information Handling (Also Spans UC2 - additional considerations pertaining to UC3 here)

This section was identified whilst researching the requirements of an archival and A&R system, and whilst not within the remit of this project, was researched so as to provide a full picture of what is required going into any commercialisation stage.As other elements of this project became more complex and dynamic, however, the decision was made to put this on hold to allow resources to be diverted to more pertinent tasks.

The following was identified, however:

A software based PTP reader was researched and is available. This would require further development to allow the recording software to interface and utilise the timing information within the file stamping process, but proves this is possible.

The method of metadata input was conceptualised and would be required as a ‘first contact’ part of the CSP UX interface when signing in/up to a service and upon subscription to an instance of connection - whether this is a rehearsal or performance.

Some data could be utilised repeatedly (artist name and copyright details for instance) and taken from the service sign up or account data, and some would need to be on more of an ad-hoc nature when instigating an instance of connection (instrument and song name for instance)

Further consideration needs to be made on how metadata and other relevant written information is collected and linked to the recorded audio, and how this scales efficiently to a UC3/Professional Production Management environment.

6.2.1.7 Audio Specific Organisational Structure(s) and Roles

From a research project point of view, the number of technical and production staff to build and run the network and audio systems was not insignificant. Upper level production staff coordinated the audio and network configurations across all three venues, and local staff became responsible for each individual venue. As the trials progressed and the knowledge base expanded, it became easier and quicker to deploy the systems. For each day on site, weeks were spent planning the deployment, which ultimately paid off with a successful showcase from the audio and network team.

6.2.2. Comments on audio test results, remaining to be tested or not able to test

6.2.2.1 UC3CReq#1 (Artists playing together from remote locations with audio and a range of visual feeds (including HD) which can be live-mixed and projected in-venue)

This case was tested during each stage of the trials and showcase. However, additional detailed and subjective listening and viewing tests would be required to collect additional data and feedback before any commercial outcome would be possible.

6.2.2.2 UC3CReq#3 (Curated experience of UC2 which can be experienced collectively via 2 options: VR Lounge and Immersive Studio. Provided by feeds into projectors as well as headsets for in-venue collective viewing)

Most testing was concluded satisfactorily for the purposes of this project. However, the below was noted as potential development from an audio perspective:

There was a comment from consortium members that when the Pearl Harts UC3 LB section had finished playing, there was a noticeable lack of audience reaction (given that this was directly from the live room in Metropolis, so had no in-venue audience to relay), which resulted in a drop in energy or decreased enthusiasm within the viewing space. It would be appropriate to investigate ways of feeding back reactions from the online audience into the In Venue setups, potentially within a 'synthesised audio' environment similar to that of Mativisions visual version.

This would enable a much more connected experience and help to more seamlessly blend with other live/collaborative material from the other 'Live Audience In Venue Experiences'.

This would also enable feedback to the artists and allow them to establish a connection with their audience.

6.2.2.3 UC3CReq#5 (Alternative experiences available for in-venue audience to create a 'festival' offer with opportunities for discovery)

Whilst the technology for this has been proven, this requires future testing and market research to evaluate the commercial and artistic benefits of festival style alternative experiences.

6.2.2.4 UC3CReq#6 (In-venue premium experience of the live event via smartphones/ headsets (for example artist pov, backstage)

Whilst the technology for this has been proven, this requires future testing and market research to evaluate the commercial and artistic benefits of festival style alternative experiences.

Table 12: UC3 Audio KPI

Requirement ID	Description	Target KPI (if available)	Last Measured Figure & Date	Final Measured KPI, Test Date(s) or Not Tested
	Testing completed/satisfactorily concluded Testing completed satisfactorily at this stage, requires further development or research Testing not required - subject of research or requires future development Testing not conducted			
UC3NReq#10	Intersite latency	5 ms	March Trials	Tested June Trials
UC3FReq#4	General purpose common platform low latency playback player			
UC3FReq#5	General purpose common platform low latency software encoder			
UC3FReq#6	Low latency equipment to be used when capturing typical content and streamed over the network		<4ms Self latency	<4ms March Trials
UC3FReq#7	Integrated audio interface/mixer/format converter to capture analogue audio (Mic/Line/HiZ) inputs and convert to AES67/Dante - 5G. Interface to include 5G - analogue for ultra low latency binaural monitoring. Interface should have at least 4 input channels and two headphone outputs.		March Trials	Showcase
UC3CReq#1	Artists playing together from remote locations with audio and a range of visual feeds (including HD) which can be live-mixed and projected in-venue		March Trials	Showcase See Above 6.2.2.1
UC3CReq#3	Curated experience of UC2 which can be		Nov	Showcase

	experienced collectively via 2 options: VR Lounge and Immersive Studio. Privdude by feeds into projectors as well as headsets for in-venue collective viewing		Trials	See Above 6.2.2.2
UC3CReq#5	Alternative experiences available for in-venue audience to create a 'festival' offer with opportunities for discovery			See Above 6.2.2.3
UC3CReq#6	In-venue premium experience of the live event via smartphones/ headsets (for example artist pov, backstage)		March> Jan Trials	Showcase See Above 6.2.2.4

6.2.3 Future Development Opportunities

RAN precision timing as relating to audio transport

When the 5G OTA technology exists to support the transmission of audio, further research into how multi-site 5G connected audio is accurately clocked will be essential. The showcase implemented GPS based PTP timing, and any future 5G wirelessly connected endpoint would need to draw audio synchronisation information from the network itself.

The potential cost savings of RAN precision timing, over the GPS solution used, are exponential as scale up gets larger. In a single instance, a labour and installation fee would be saved, as you add more complex scenarios into each 'node (end point for packetised audio over the 5G network), and any redundant nodes will represent additional savings in time and complexity. This would mean each node would require no additional hardware and would become "plug and play".

Future Audio System Development - Audio Network

Whilst there were many choices of network protocol to use, and some might have been easier than others, the choice to run AES67 / SMPTE2110 was based purely on technical choices. It's also worth noting that there is extensive crossover between some of the protocols available (Dante, AES67, ST2110, Ravenna) and for our application, the final choice could have gone several ways. The use of multicast audio gave us bandwidth efficiency, which is likely to be essential in future wireless applications of this technology, but proved more technically challenging. The decision to utilise network protocol also took into account the open nature of Advanced Encryption Standard (AES) and Society of Motion Picture and Television Engineers (SMPTE) standards (co-developed by working groups from multiple manufacturers) rather than committing to one "standard" primarily adopted and developed by a single manufacturer and controlled for commercial gain.

6.3. Showcase Ticketing Solution & Venue Integration

January / February 2022 Trials

For the January trial, we created a single event for the online-attendance variant that issued unique 10 character alphanumeric codes against each ticket registered.

Access codes were distributed in real time to the registrant, with a customised email that included instructions on viewing the stream via the web application.

A Single ticket type was enabled with the customer selecting the stream type in-app following code validation.

As mentioned earlier in this document, the video application may have the opportunity to include several user selectable streams and issuing different ticket variants to support this functionality is in scope.

All tickets were free of charge to register, and the payment system was bypassed to reduce registration time / unnecessary data collection.

All registration data is handled in the UK and is subject to GDPR compliant data operations.

Showcase Event

With attendees at each of the 3 discrete venues, the invite / access process varied significantly for the in-person experience. However, we were able to simplify the online ticket distribution and issuance of an NFT for proof of attendance, and this was standardised across the event – an important consideration for any service seeking to offer this type of online event is customer support for online event attendees. At late notice, we were required by one of the performer's management to artificially limit the number of "online only" viewers to 100; for any commercial application the online capacity would not be limited.

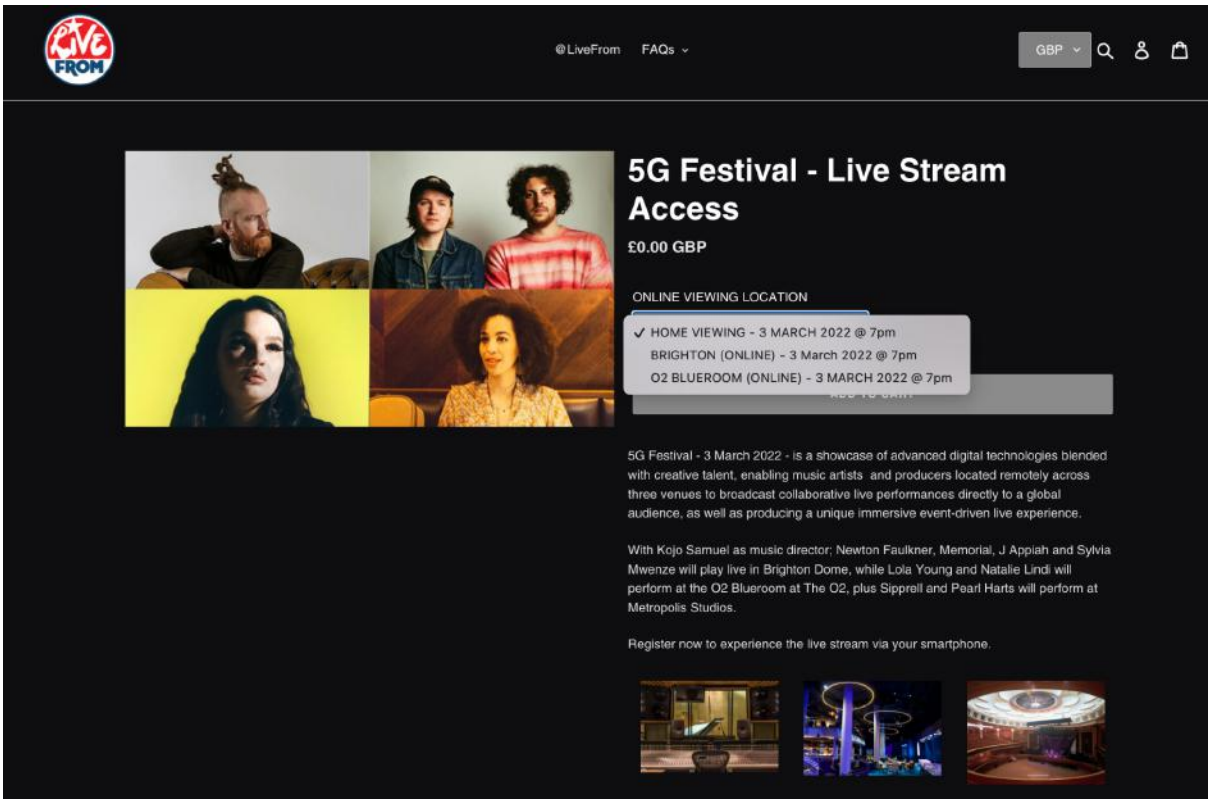
Brighton Dome (cap 800)– The ticket distribution for the in-person attendees (maximum 800) was managed by the in-house box-office resource at the venue in the same way that any event takes place. This ensured that all of the data / safety / venue / messaging procedures were followed for this cohort of attendees. Attendees registered online and received an e-ticket, as well as a link to register for online viewing. This was the simplest way to distribute online tickets to in-person attendees without requiring data-sharing and to avoid exceeding the online only capacity.

O2 Blueroom (cap 100) – Whilst this venue is typically a fully public space, and has no formal box-office, the guest process is well established.Invitations were sent with a running guest list for access at the venue and guests were sent information about the event plus a link to register for online viewing.

Remote Attendee / Online Viewing Ticket Access (cap 100) – We deployed a similar approach to the successful January trial. A single registration event was created, this time with 3 ticket types – one for each of the showcase venues (with sufficient capacity to provide for the max capacity at each venue) and one for the online only remote viewers. The

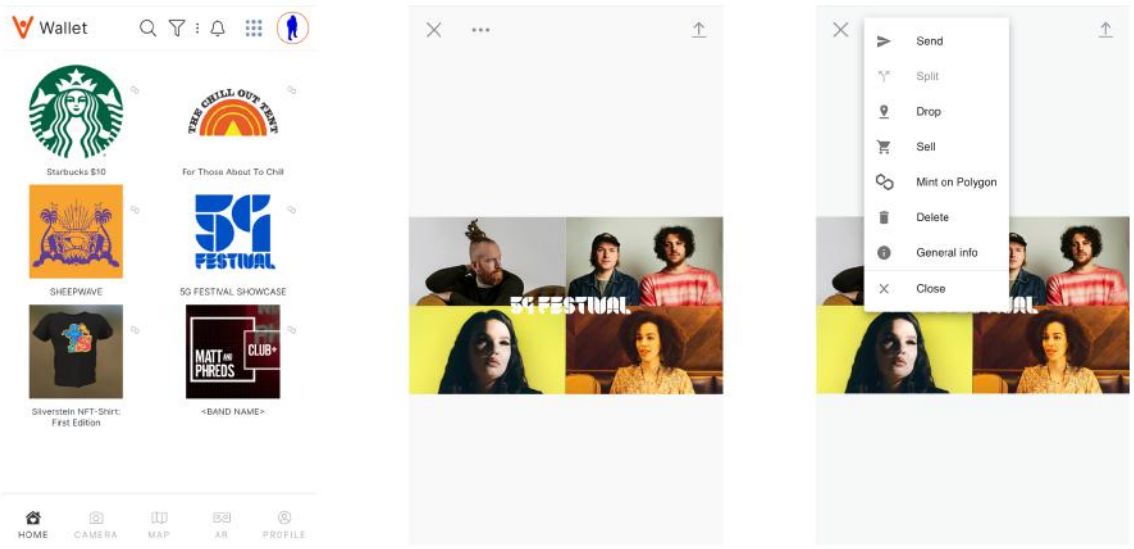
registration link was distributed with e-tickets to Brighton Dome attendees, to invited guests for O2 Blueroom and Metropolis, and internally to consortium invited guests who made up the online only cohort. In total, 138 online viewing tickets were registered.

Figure 39: Audience Live Steam Access



Proof of Attendance NFT – We tested two services and used one for the showcase event following a successful proof of concept during the January trial. We configured the distribution mechanism to be from a single link, but limited to one acquisition per registration.This meant that we were able to present a simple “claim NFT” button on the same viewing page as the remote stream. This triggered a process by which the user was asked to register their email address to claim their NFT, which was then delivered to the wallet that was created for that email address. The NFT was a simple JPG featuring the poster image for the showcase event. The wallet object icon was the stacked 5G festival logo. The token was issued on a practically no-cost sidechain with the option for the acquiring user to mint the NFT on Polygon if they wish. 83 Proof of Attendance NFTs were issued representing 60% of the remote ticket holders.

Figure 40: Interface with proof of attendance NFT wallet



Ticketing Summary

Overall, the ticketing solution design for the remote viewing was complicated by the separation of the ticket distribution and the access control for the remote player. The additional complexity of enabling in-person attendees to simultaneously have access to the online stream was ultimately solved with a self-service mechanism.

For commercial application, and subject to the appropriate music / video licensing, it would be more typical to also offer a short (under 48 hours) post-event video on demand period for online viewing.This has the benefit of increasing ticket sales which was out of scope for this event but is an important consideration for commercial use.

The blockchain solution, using a proof of attendance model, rather than issuing tickets onto a blockchain directly, meant that tickets could have been distributed through multiple channels with no additional development work or integration – whilst still offering a consistent blockchain component to the event attendees.

Areas for further investigation and improvement would be simple in-venue call-to-action to acquire a remote viewing ticket and in person proof of attendance – a simple mechanism using QR codes either physically printed or more likely on digital signage / stage screens.

6.4. UC3 Project Summary

6.4.1. Video

The critical aspect of the CSP and video streams for UC3, that enabled the artist and production studio in UC1, and remote audiences in UC2, was that this experience was stable, immediate and translated well to the narrative of the live event.

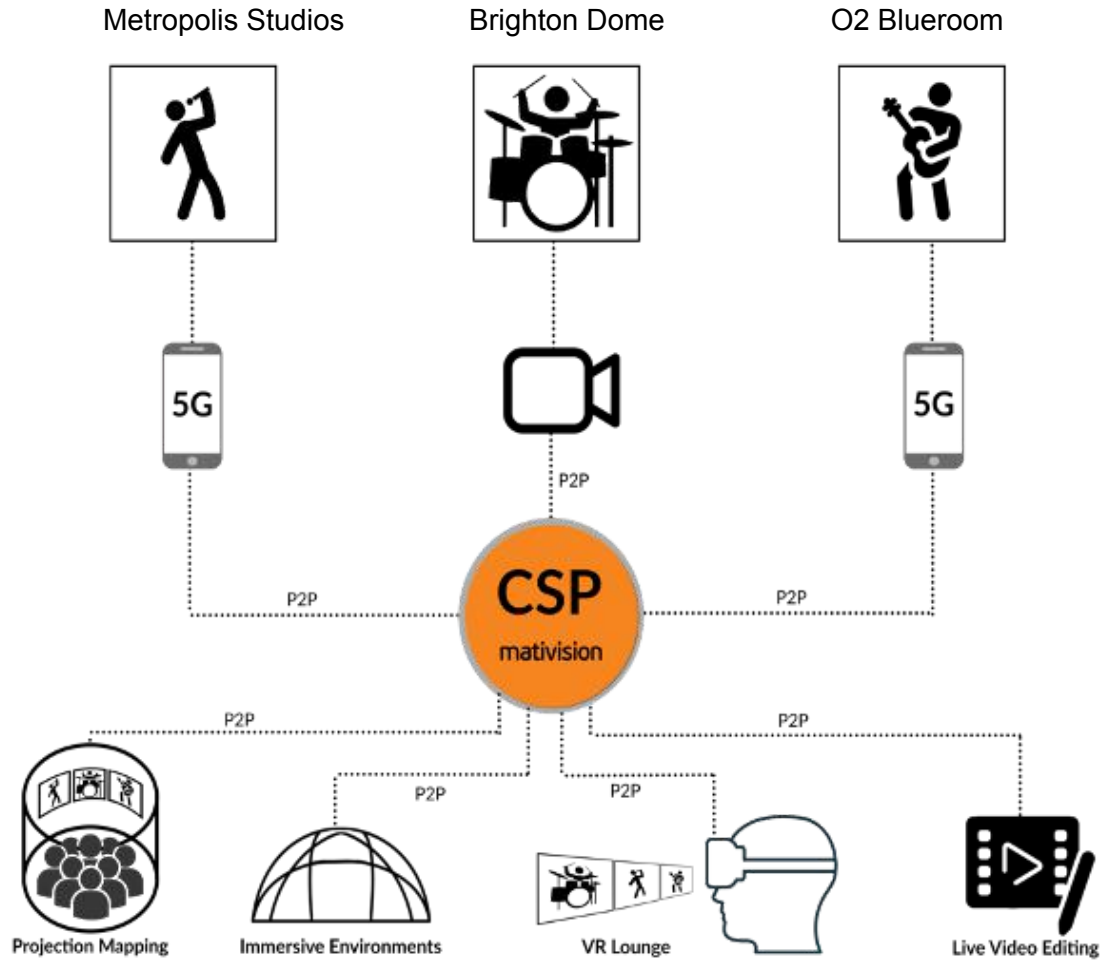
In the main, this was fully achieved and experienced in a highly successful and well regarded showcase live event.

No down time or drop out was experienced, with no call for the robust and detailed fall back plans for the show production. The experience across the 3 remote venues was handled and delivered across multiple, simultaneous streams to an impressive audio-visual hybrid, world first metaverse music event, which was publicly viewed with tangible excitement at the Brighton Dome.

This is just the beginning; more work needs to be done in evolving the concept of a hybrid festival organically by different live event use cases, fulfilling the wishes and needs of the artist, production team and audience in curating the events to encapsulate the audience of the future.

This was by no means just an R&D showcase event. The entire consortium delivered a commercially viable, public live music event that will be remembered as a world-first 5G enabled music event from the leading talent and companies in the UK entertainment industry.

Figure 41: UC3 Architecture



6.4.2. Audio

When Audiotonix was offered the opportunity to join the 5G Festival project, we immediately saw synergies with our current work and also opportunities for the future, namely:

- To help expand the live audio experience for artists, musicians and audiences, particularly after COVID
- As a strong supporter of #WeMakeEvents, we saw this project as a further opportunity to accelerate industry growth post COVID
- To help support artists' and musicians' creative ability in a virtual environment
- To expand and increase knowledge across both existing and new technologies
- To learn more about 5G; and to work in collaboration with a leading Group of UK companies in this space and deliver something truly new, world beating and relevant to today

Whilst we did not enter the project with any preconceived ideas on how we might commercialise the technologies we developed, we were confident that we could help deliver on the requirements of the 5G Festival.

It is clear from the Festival event that, as a 5G Festival team, we were able to over-achieve on the vision we had originally set ourselves, as evidenced throughout this report. The core network and audio technologies, as well as specialist knowledge, provided the foundation on which the 5G Festival was built, delivering seamless audio networking and a truly believable multi-site audio experience for both the musicians and the viewers across all 3 user cases.

There is a long way to go to make any of the user cases commercial products, from both an understanding of likely commercial business cases to the underlying technologies. We therefore consider that more work needs to be done in the following areas before we can fully capitalise on the work we have done on the 5G Festival and move towards serious commercialisation. These areas are:

- Exploring opportunities to improve and develop the 5G Festival technology platform further to work with other open market solutions
- Exploring expanding the audio platform to other DCMS 5G projects and other open market opportunities to widen the use cases for the technology
- Working to ensure seamless commercial integration with 5G OTA technologies (e.g. network slicing, global 5G usage, PTP clocking, multicast etc)

6.4.3. Venue (BDBF)

As a venue, seeing the success of the showcase event was very inspiring. The opportunities for the future use of what we undertaken for this project are many; ive multi-venue performance, co-located performances and multi-location rehearsals are the top -evel possibilities.

As BDBF has a remit as an educator and major arts festival, we mainly operated outside the bricks and mortar that we hosted the 5G Festival in. This means that the next tranche of opportunity covers teaching music; we have currently reached 5000 musicians every week. There are also further opportunities for collaboration with international audiences and cultural organisations (push and pull).

The offer for immersive theatre and other arts forms, with the extreme low-latency we have honed, is also very exciting. The bounds of possibility for creators have now expanded vastly off the back of this project, and we look forward to the conversations that will now surely start.

BDBF - Production Manager view

“For me, as the Brighton Dome and Brighton Festival Production Manager, the 5G project was an interesting one to work on, but one that, as a full product, would not be useful to us in the long-term future without significant funding behind it. For your standard touring contemporary music show, the speed of set up and the cost of the equipment involved would probably be the major dissuading factor in use. Various elements within what we did might make a show more interesting, but these are more likely to be implemented by shows that already have a longer get-in time– for instance, contemporary dance or theatre productions.

Personal immersive monitoring for the musicians has more benefits to recording artists collaborating across remote spaces than it does to a live performance (except in these special occasions where remote collaboration is wanted/needed).

The main benefits are proving that the immersive system in space is something that works really well and sounds amazing. It would be a very useful artistic tool for theatre and contemporary dance or interactive art pieces.

Providing more interesting and immersive routes to access shows is also very beneficial, not only for audiences with limitations on their ability to attend a traditional event, but also in terms of the environmental impact of audience travel and the potential increase in ticket sales/capacity through the virtual medium.”

Negatives: Long set up; would be expensive to stage; a lot of crew and equipment to make it work.

Video not reliable to sync with audio (latency).

Low-capacity audience in the space.

Immersive sound systems would require permanent installation to be cost/time effective.

Positives: Looked amazing with cameras and video projection in the space.

Great for accessibility to give the audience more choices on how to engage (VR at home for instance).

Alternative stages and the viewing room worked well and this would be useful for a more ”festival vibe” and to cut emissions from travel to other cities.

Immersive sound system in the space sounded amazing.

Further thoughts.

It would be interesting to see further research and development in the areas of better synching between remote video and audio.

It is probably beyond the ability of the bandwidth at the moment, but it would be interesting to be able to introduce AR glasses to the audience in a space, alongside a remote collaboration of artists. The audience can then get a feel of the other audience, as well as the band, perhaps with the ability to select camera views as part of that e.g. choosing to watch a specific band member from another remote space rather than relying on the curated content on the big screen in any particular space.

Audiences of the Future (3rd Person Professional Perspective) - Nick Young

“With this use case, the challenge was to create a seamless high-quality live experience, but that also communicated the advances in technology that have made what was previously impossible, possible.

The risk is that the moment you begin explaining or pointing out how things work, you lose the parts of your audience that don’t geek out on knowing all about the nuts and bolts. They then become less immersed in the event, and come away feeling like they had a lesser experience artistically than is warranted by the actual quality of the acts.

That said, you also want to present the performances in a way that really makes use of the fullest capabilities of the technology and gives the audience(s) an experience that they’ve never had before, and in doing so open up the magic of the creative technology set-up, backend, software, and hardware, experientially. Some of the points below are not directly linked to the technology, but as they featured as part of the audience experience, I have included them anyway.

The live experience in Brighton Dome (BD) was an end-on setup, using the stage and auditorium in a classic gig/concert style setup. The shift in focus for the audience between BD and the other venues Metropolis Studios, and O2 Studios in London, was achieved by ‘moving’ between the venues using projections with coloured borders to demarque the location.

During setup and rehearsals, I had concerns that these transitions would be clunky and that lag times from video feeds would cause slumps where nothing may be happening for periods of time, even if only short. But these fears proved misfounded by the final event, a testament to the entire team and stage management of the event.

The only bump was when the Festival temporarily diverged into 3 separate events before coming together again (see below), which whilst maybe not executed seamlessly, has to be applauded for its ambition in testing the potential of the setup and audience experience.

The audio was great. As you would expect from a major music venue, the quality of the hardware was excellent, but the addition of spatial sound to create a 360 sonic experience was fun, often thrilling, and put to good use in an economic fashion that kept it fresh and entertaining.

Did the projections convey the fact that we were watching multiple artists across multiple venues clearly enough? The size, spacing and quality of projections says no. The borders, whilst helpfu(if you knew what they meant), probably didn’t communicate much to the audience.

What was achieved in UC2 around the presence and status of performers felt, at times, oddly lacking in the live event. People who are physically in front of us will always naturally command our attention more than those on screens, and so the artists who were being beamed in should have been given more oomph by bigger, clearer, and more innovative in-venue visuals. The lack of a back screen felt like a wasted opportunity.

There was a point in the evening when the festival split into three temporary independent events to showcase UC2. This didn't feel planned well enough and wasn't communicated to the audience as clearly as it could have been. The result was a loss of energy and people from the auditorium, plus a bit of confusion around where people could or should be. It felt like momentum was lost. But as someone said on internal comms, "Hey it's a festival, people come and go from stages."

Perhaps I have been overly harsh - I hope not. I have tried to toe the line between critical expert eye and audience layman. I think that the final word has to be that everyone who attended as an audience said and demonstrated that they were having a really good time; and everyone who worked on the project that I spoke to had a sense of immense achievement and satisfaction. And so, teething problems aside, especially as an R&D project that massively over-delivered with a professional 5G live music event, the 5G Festival of 2022 was a resounding success."

6.4.4. Overall Audio & Video Experience

The use of live in venue spatial audio, via the d&b Soundscape system, in both the Brighton Dome Concert hall, the Blueroom at the O2 and in the Founders room at Brighton Dome, for UC2, meant that the audience watching the show were able to hear a much more detailed a nuanced version of the music.

Because the d&b Soundscape system is object-based, it meant that we were, to a degree, able to place the audio coming from the individual musicians (live on stage and from the remote venues) in the positions they were being shown on the stage and on the projection screens. However, as has been mentioned, due to the size and positions of the screens, in both the concert hall and the Blueroom at the O2, and the poor quality of the projections, the mapping of the audio to the video didn't always make sense and the borders around the screens didn't really help the audience realise that many of the musicians playing were in fact 70 miles away in a different cities.

The advances in spatial, object-based, audio for live productions has come on leaps and bounds in the last few years and it is now possible to create amazing audio experiences, where the audience is not even aware they are listening to a sound system, as they would in a typical stereo set up, because we are able to place the musicians, vocals and FX in a 3D space and trick the audience's ears into believing they are hearing the sound coming from its original source.

If we can now work on improving the visual aspect of this and, for future concerts and showcases, experiment with the use of volumetric capture and holograms, then we can

combine the real and virtual musicians on stage together as if they were all, not only in the the same band, but on the same stage.

Moving forward, from an audio point of view, it's important that we learn from what we have achieved, improve on the advances we have made during the project (live, UC3, and broadcast, UC2, audio) and work much more closely with the video aspect of any future trials and showcases so we can create exciting, emotive, fully immersive, audio visual experience for audiences and musicians in remote venues.

7. Technical Feedback

7.1. Audio Technical Feedback

The Audio department met the requirements of the original brief and, through the deployment of the latest technology from Audiotonix, provided an audio experience that matched that of a single venue performance for both the musicians and the audience.

The latest DiGiCo mixing consoles and interfaces offered the flexibility to handle the complex signal routing that resulted from the 3 location setup.

The audio network was configured as 4 discrete “locations” across 3 physical sites using Calrec AoIP interfaces; making the 3D studio its own location made the deployment easier but increased the bandwidth used. There was capacity within both the hardware used and the network, for higher channel counts without compromising performance.

Klang Immersive Monitoring systems proved essential in combating the inter-site latency. During initial trials, when we deliberately pushed latencies up beyond our expected limits, the Klang system allowed the musicians to continue to perform. With the final 10ms latency, Klang made the latency virtually invisible to the musicians.

While this unique setup over-delivered on the audio expectations, it required extensive management and engineering skill. Further testing and work is required to develop these technologies into a system which is easily deployable for future events.

The wider leased-line based network may ultimately become wireless using OTA 5G technology. Whilst limited testing did occur, much more work is required to overcome the technical challenges and make this a viable future commercial solution.

Whilst UC2 AME/Autonomous Mixing is highly beneficial within that context, it is noted that the ingest and mix structure implemented for UC3 was necessary as this provided the much needed flexibility and control over what turned out to be a very complex and dynamic creative offering.

The ability to service the many output paths using a single mix point was clearly an advantage and let the engineer focus on the quality of the mix, rather than the quantity of mixes, and be confident that the various renders required would translate well and effectively across all the deliveries.

Some points raised by the engineer on the hub input side were the ability to view real time footage of the broadcast mix, which is usually commonplace in this type of work, so that the engineer is able to respond to changes and cues in a preemptive way.

This is not a comment on the CSP, but a thought as to how complex this scenario is and the technological requirements that are still to be achieved in this area.

Whilst possible to delay the audio to these visuals within the monitoring environment and therefore be able to match fade timings etc, it is not possible to do the same thing with the communications audio, as delaying these would lead to overall confusion and lack of responsiveness by the engineer.

It was also noted that the sync process for alignment when recording was very manually intensive - a clapper board and sync type as there was the inability to 'gen lock' or stripe timecode to the video feed. Being able to sync these in a much more automatic way would be a great addition to the next iteration.

On the whole, the output systems had a positive response in terms of quality and engagement, being aided by the audience capture systems to enable a 'live' feel to both the online audiences and the remote venues, although proving to require more technician/engineer input than first anticipated. This is not something that detracts from the premise of these systems, it just highlights that there is still a good amount of work to do, but can be achieved and would likely be received well.

It is noted that an object-based rendering system would be beneficial to both UC2 and UC3 scenarios and that a 5G infrastructure would enable the bandwidth and speed to deliver the requirements involved.

7.2. User Experience Feedback

Frontend App

Overall, the front-end app successfully handled its requirements for the tests and showcase as a minimum viable product (MVP). Further testing and enhancements are required to use the application for larger-scale events.

iOS 360 stream issues - It was reported during the showcase that iOS devices were unable to view the immersive stream, with a blank screen or decoding error presented.

The stream has been previously tested on iOS devices successfully using provided demo and live streams, along with online video testing streams.

The reported issues could be replicated during the showcase with no obvious cause. Further testing resulted in successfully viewing the **linear** stream and various online demo streams in the 360 immersive player on iOS devices.

Post-showcase analysis suggested that the cause may have been the native iOS support for HLS video streams, when the segment files are above a certain size. It's likely this was triggered due to the complex nature of the 360 immersive stream.

There are minimal options for processing HLS streams on an iOS device without using the native support. Future recommendations would be to test this again with a complex live stream to first replicate the issue, and then test again using a non-native HLS library.

7.3. Future enhancements

Enhanced load-testing - For larger events, other server solutions may be more efficient and cost-effective when run at a significant scale. Appropriate load-testing should be performed to first validate the existing solutions capability vs cost, before then testing against alternate server architectures.

Enhanced security - All live stream files are currently passed through the internal server for access control and security reasons. As these files are converted from the raw stream URL into absolute paths, it is feasible that a user could ascertain the root domain of the raw stream, and then access/share the stream without requiring an access code session.

To combat this, a secure, shared and encrypted access bearer token should be used between the internal server and the raw stream server, to validate a legitimate access request, and significantly limit the above scenario.

'**XR/VR Lounge' -** Emotive experience compared with traditional methods of delivery. Comparisons between group/shared experience, single mobile use and single 'HMD' experience.

7.4. Video UC1-3 Feedback

The CSP delivered video over the network in low latency. The CSP was used multiple times over the initial scope of devices and uses. There is still more to be researched into how each device has its own local latency. The 5G Galaxy Note 20 cameras proved to be the least latent of all but were still measured at ~100ms between an event happening and it appearing on screen. The phones tested had 120hz refresh rate screens, which reduces latency and thus means that the latency is in the camera hardware itself. The depth camera planned for UC1 had over 200ms latency, which made it unfit for the low latency requirement of the project. The broadcast equipment for UC3 also had the same issue with different cameras, capture equipment had different latencies.

The distribution of content via the CSP achieved low enough latencies to be almost real-time with the delivery of content being measured at 30-60ms depending on the distance between the two devices.

The first iteration of the CSP used an application to encode and decode content. The nature of the applications meant that for every update, the application needed to be re-installed. This meant that iterations were slow, as the application needed to be installed on multiple devices and also the Nreal headset needed a separate build. The use of a webapp on the second version of the CSP proved to be highly efficient with a simple refresh providing the latest version on all connected devices. There was a scenario where multiple high bitrate videos requested from the same device would cause high CPU usage on mobile phones. In a future iteration, a global bandwidth monitoring software would need to be in place to monitor each stream going in and out of each device and to regulate traffic based on the network connection of each device.

8. Live Event Production

Show Management and Running Order.

The UC3 Showcase event posed us with new unique challenges to overcome within the planning of a live show.

For a broadcast event, it is quite common to have a main event production in a venue with added satellite sections . For home viewing, the experience is seamless, and for those in the main venue, they are relayed the broadcast video and audio so that they can see the performance. An example of this is The Brits 2019 where the main event was inside the O2 Arena with the opening artist, Coldplay, performing on a barge on the River Thames opposite the O2 Arena. The Coldplay example is a separate technical setup in terms of cameras, lighting and audio etc. and during the show, the floor manage team cue in when the performance should start.

The 5G Festival project work will definitely lend itself towards productions like the Brits 2019, where these remote performances are required to be connected back to the main event. Using the 5G network would eliminate the constraints found today in picking these locations and the need of satellites and dark fibre connections.

The 5G Festival showcase scope took the above one step further, involving more than one live audience at the venues in question.

Brits 2019

- O2 Arena - Live Audience in front of stage and video
- River Thames - No Live Audience, maybe some VIPs watching, but they don't get any content from the O2 Arena Main event
- Broadcast - Home Viewers

5G Festival Showcase

- Brighton Concert Hall - Live Audience in front of stage and video
- O2 Blueroom - Live Audience in front of stage and video
- Metropolis - No Live Audience but some VIPs watching video (also in the 3D Studio) as part of 'home viewers'
- Broadcast - home and remote viewers

There are obvious similarities within these lists, but the key difference is that the 5G Festival had two venues with live audiences who were coming to see a seamless show within that

space. The scope of the project isn't about delivering a remote part of a main show to the O2 Blueroom audience.

The cast for the 5G Showcase was built up from 21 Artists across the three venues.

Metropolis - 5 Artists
Bass, Perc, Vocalist and a Two piece band called Pearl Harts.

O2 Blueroom - 7 Artists
Electric Guitar, Four Piece String Section, Two featured vocalists Natlie & Lola.
(Natalie also played acoustic guitar)

Brighton Concert Hall - 7 Artists
Drums, Electric & Acoustic Guitar, Keys, Two Vocalists and a featured artist Newton Falkner.
There was also a DJ for pre / post show and changeover moments to keep the crowd entertained.
For the showcase, some of the artists had been part of trials going back to March 2021, so it has been interesting to see how they have watched us develop the technology and see the end goal of a showcase become a reality. Their feedback has been greatly valued.

As the artists became more familiar with the technology platform and peripheral devices, the enhanced experience on offer became a valuable toolset to enable their seamless, remote live collaboration capabilities.

Whilst working on the running order for the showcase event, we had to take into account the viewpoint of the audience from each of the venues. As such, there were different modes in which the show would operate within and these had an affect on what the audience in venue and audience remote at home or on devices consumed as part of their experience.

Table 13: Showcase Output per Venue

Mode / Venue	Metropolis	O2 Blueroom	Brighton Concert Hall	Broadcast Output In venue / On Device
1	Band Collaborating	Band Collaborating	Band Collaborating Lead Vocal	Cameras from all venues.
2	Band Collaborating	Band Collaborating Lead Vocal	Band Collaborating	Cameras from all venues.
3	Band	Band	Band	Cameras from all

	Collaborating Lead Vocal	Collaborating	Collaborating	venues.
4	Solo Performance	Video/Audio relay of solo performance	DJ playing during changeover on stage.	Cameras from solo performance.
5	Solo Performance	Solo Performance	DJ playing during changeover on stage.	Cameras from one venue, the one decided as the lead performance.

Modes 1,2 & 3 were similar for the June and November trials during the project where we had a band separated across the venues collaborating simultaneously. We had aptly named this band “The Remotes”.

For modes 4 and 5, elements were more divided, and it was within these modes where the new unique challenges of putting on a show emerged for our Show Management Team.

For Mode 4, we had intended for there to be a moment in the show where each venue was consuming a separate experience.

Metropolis - Pear Harts - a two piece Rock Band performing their own set.
O2 Blueroom - an in-venue video and audio relay of the Broadcast output to the audience.
Brighton Concert Hall - A DJ Changeover / interval while on stage musician setup was being changed. This also allowed time for the Brighton audience to visit the Founders Room, which was setup as an in-venue remote viewing room with a screen and Dolby Atmos audio output.

With all live performances, technical issues occur and never usually at a beneficial time; 30 minutes before the show, we had a technical issue with the broadcasting setup and the way the Dolby Atmos feeds were being embedded. After every effort was made to fix the issue, at the last minute, before the show commenced, the decision had to be made not to make changes that would risk the rest of the show and we had to scale back in the technical output.

As a result of this the Mode 4, became Mode 5:instead of the audience in the O2 Blueroom seeing the Pearl Harts, they were given another opportunity to see Natalie perform solo on the acoustic guitar.

It is worth highlighting how making a change likethis brings in new thinking for the Musical Director and the Show Management Teams. During the Showcase event, he Pearl Harts set consisted of 2 songs which ran for 5:25 and 3:35 minutes:seconds respectively, a total of just

under 9 mins. With Pearl Harts being the lead performance at this moment in the show, it then had to be worked out what Natalie could do to fill the time available. Natalie had two songs totalling around 7 mins, which then meant her needing to talk before and after the songs. However, as much as this sounds like a very simple process in practice, without rehearsal the Stage Management team in O2 Blueroom had to talk Natalie, via her in-ear monitoring, during these times so that a seamless handover happened, putting the O2 Blueroom into the main show running as Memorial went on stage in Brighton.

The fact that this change had to happen 20 minutes out from the show starting shows how hard the team who were facilitating this event had worked to understand the challenges around the multiple simultaneous show with one core team.

WP4 Production Management

For overall project management, new challenges became apparent around aligning the workings of three separate teams. The structure of a WP4 PM overlooking each venue's own teams proved to be a good working method.

From a practical point of view, being able to travel to each of the venues certainly helped to understand the individual challenges and enabled us to help align them across the others.

Using the final trials week as a rehearsal was very beneficial in maximising the time we had available on site with all of the teams and expedited the setup during the showcase week.

Communications

As reported in MS6B, it was noted from previous trials that communications between venues and departments was a key element that needed to be improved on. For all shows, the communications setup is a key part, across venues this became more critical.

Team Audio, a communication specialist company, was contracted to provide a communications system across the three venues and the teams within them.

The Comms System was built using Reidel hardware which is very well respected and used widely across the live music and sports industries.

Each venue was supplied a master matrix interface that connected everyone internally within each of the venues. There were 3 types of connection a user could have depending on their circumstances.

1) Panel with mic & speaker, or headset, for those in fixed locations. A panel had 16 talk buttons for personal assignment
2) Wireless beltpack with headset for those on the move. A beltpack has 6 buttons for personal assignment

3) Mic and foot switch, for artists. These were fixed to the artist group

Ordinarily, communications systems are used by the crew and those working behind the scenes. It has become common practice for artists who are using IEMs to have talk mics and create the ability for artists and the musical director to talk each other via the sound console. Each artist has a microphone, ideally a switch mic, and they hear each other via the sound consoles. For the showcase, Team Audio came up with a solution which allowed each musician to have a mic into the comms matrix and a footswitch to control the on/off of that mic. Out of the matrix, there was then an output which was fed into the Klang interface via Dante which allowed their own person volume control of the party chat.
By adding the artists into the comms system came with several huge benefits such as:

1) Allowed for more instrument inputs on the monitor consoles
2) Crew could hear artists within their comms channels
3) MD could speak to crew and artists via one control panel
4) Artists could be split into per venue groups for when the show split into separate performances

Comms systems chat groups were made for each department, such as artists, show management, lighting, projection, cameras etc; users could decide what groups they wanted to access by pressing the buttons of their devices, and could hear the chat within those groups and join in by pressing their talk button.

There was a group title dhow and every user had this on their device. This was the main comms channel used for running the show. During the show, all artistslisten in to this channel for cues and information and could simultaneously be separately talking to their own teams.

It was also possible to have a button linked directly to another user. For example, the showcaller in Brighton could have a button that linked directly to the showcaller in the O2 Blueroom as a direct connection; no one else could join this chat as it wasn't a public group.

To join the venues together, 8 channels of AES67 audio were connected between each of the venues. This allowed for 8 group chats to connect across the sites at any time. These are allocated by the system on a round robin basis.

Across the venues there were a total of 90 users on the comms system.

Brighton
8 x Desktop Panels
24 x Wireless packs
7 x MD & Artist Mics

O2 Blueroom
4 x Desktop Panels

16 x Wireless packs
7 x Artist Mics

Metropolis
4 x Desktop Panels
16 x Wireless packs
5 x Artist Mics

As a technology project centred upon networks, and having had our fibre network crash out at times, the comms system needed to have a fall back solution. For this, Team Audio set up a separate internet based comms solution which was then integrated to the Reidel system. This system used cable based internet in each of the three venues and was simultaneously running at all times. Should the main AES67 connection via the fibre network stop working, the internet solution allowed for the main Show channel to stay active for everyone so communications could stay in place whilst a fix was found.

The ability to combine venue comms on our network and internet comms also allowed us to connect to the London Bus used during the presentation day. Users on the bus were able to download an app which allowed them to connect into the backup system and talk to users in the venues. This allowed us to ensure the band were playing songs for the live demos on the bus and discuss any technical issues or successes happening on the bus in real time without needing to make separate phone calls etc.

Team Audio played a valuable part as a 3rd party supplier to the project and their time with us making it all work was well spent. They joined us for 2 days of audio testing at Metropolis to prove the network connections could work on a Layer 3 network. They also attended our trials week testing across the network and enabled teams to communicate . For the showcase week, Team Audio provided the backbone to run a show across three venues 70 miles apart, including our moving bus.

Team Audio's Lessons Learned

As a 3rd party supplier to the 5G Festival project, the members of Team Audio have taken away some valuable learnings in how to support crews and artists across multiple venues, the benefits of 5G connectivity for comms systems in the future and proven a new working practice for connecting musicians and crews together.

Team Audio are a comms company specialising in connecting people. Where the 5G project at the outset was seen as three comms systems joined together, in practice, it was actually more. The physical equipment was made up of three duplicated systems placed in the three separate locations, but how they were managed became more of a collaboration. It is standard practice to have a comms engineer with the system to manage the hardware and create the software connections to allow the conversations. However, significant planning

was undertaken at the beginning of the project and there were always tweaks and changes. For the 5G project, each of the venue's engineers found that they were having to make decisions based on requirements and considerations for the other venues, and sometimes the obvious wasn't the actual answer;this included simple things like naming conventions. One engineer might call lighting "LX" and another "Lights". Names like these needed to be consistent between venues, so if anyone referred to a particular grouping, they were not confused by different abbreviations or jargon.

From the outset, there was always going to be a main Show channel. This was designated as the main channel for running the show. As a collaborative show, it was seen that the show management teams across the venues would use this channel constantly during all of the rehearsals. In practice, it was found that each venue's show management team also needed to speak internally at times to avoid confusing the other venues. This resulted in more groupings than initially planned, but to achieve a much more efficient way of working. The interlinking of the venues had 8 audio links; they worked as a round robin assignment as required by the connections created in the system. Although these weren't maxed out at any time, it did come close. For future projects like this, having 16 links will probably become standard.

The bus connection had been imagined as a few people on the bus being able to chat together, with a link back to the main show caller. In practice, this expanded to be a lot more, but in a natural way within the context. The bus moment was unique, and yet with the challenges of not being able to dry run that it was very much spontaneous, but the system had the features and the bus team were able to connect to the PM and show management teams in Brighton, Phil mixing the audio for UC2 being viewed on the bus and Mativison and the video teams seamlessly. Although the bus went into a low signal area inside a tunnel, the comms still got through without any dropout. This moment within the project was a great thing to have made work as, undoubtedly, Team Audio will be asked for this again one day. Maybe not on a London bus (but who knows!).

5G technology is going to bring about significant benefits to comms and connecting teams. Technology today has lots of solutions for connecting people via the internet, but they don't meet the requirements for the entertainment industry. You cannot get away from show comms needing to be facilitated via headsets that block out noise and allow people to connect in groups, or one to one within a simple hardware solution.
5G technology, to be able to connect the system between locations, is going to be invaluable and, where the bandwidth capabilities of 5G might not be needed, the low latency and ability in the future to guarantee bandwidth across the network, the use of cables will soon be redundant.

Whilst drawing up the design for the system, a requirement was to build in the musician talk elements to avoid using up valuable sound desk capacity, creating the traditional artists talk. There has always been a divide in how artists have a talk system in the monitor desks, and the crew are using comms systems and making them interlink properly never quite works.

The 5G comms system treated each musician and crew person as an user on the system with their own input and output assignment. Initially, at the trial in Metropolis, the musicians were given a desktop panel which had a microphone and a footswitch to control it. They could select on the panel who they need to speak to. This proved to be an over-engineered solution. For the trials week, this was turned into a microphone, with a footswitch and not panel control; musicians just needed to be in one big party line group. Key people, such as the MD who needed to talk to crew, were the ones to really benefit. As they didn't have two systems to manage, their panel allowed them to talk to who they needed to instantly. This learning is going to be a solution team audio will take forward as a standard.

9. Questionnaires - Feedback (Artists, Audience, Technicians)

The feedback for the Showcase event was not dissimilar from the trials feedback, but had extra considerations with regards to the audience, with feedback forms being completed by some consortium members.

Taking the audience returns that can be regarded as non-consortium members, we have the following observations/responses:

- The quality of the audience was considered to be very good.
- The latency of the audio also impressed.
- There were some question marks over the term “immersive”, with not many aware that there was an immersive element and some confusing the “immersive” as being something you would solely experience with the VR headsets.
- There was a feeling by those who knew more about what to expect from the “immersive” elements, that its main purpose was to highlight that immersive elements were there. But these comments did add that was to be expected, given the “demo” nature of the project.
- The quality of video was criticised but was regarded as above average.
- The latency of the video in the main concert hall drew the most negative comments. The latency in the Founders room scored a better mark.
- The desire to attend future hybrid experiences was mixed, with some saying it was fun but the full live is better; some said it was fascinating and they would definitely go again.

Some consortium feedback wholly dismissed the set design and the use of triangular screens. There was also a consortium comment questioning projections on the ceiling; the audience, however, specifically mentioned the ceiling work as being a highlight.

In the February trials, comments were made about the lack of indication of location via the set design. This was no longer an issue at the Showcase event.

The artists/musicians

This is based on feedback from the final trails in February, as no feedback forms came back from the musicians following the showcase event:

The musicians did not feel there was any noticeable increase in set-up time.

They reported intermittent displays of other musicians on the phones.

One quote here in full, as it has some good suggestions:

“Phones displaying other musicians (these didn't work consistently), Klangs and challenges with communication caused by only one person being able to speak at one time, since we

were all hearing the same talkback channel, made the session much more complex than usual. As it was, these questions had to be directed to the entire group and would prevent anyone else being able to continue working. This could perhaps be remedied with sub groups of talkback channels which emulate the ability to simply turn to one musician and ask a question or discuss a part of the song. This could be done in sections eg band, strings, backing vocals etc or with some other relevant groupings. Once I was comfortable with the Klang that was fine but I found it frustrating that very simple actions such as muting your instrument to other musicians so you can work on a part silently was difficult to do. This meant that if a sound or part was being worked on, everyone else had to stop as they would be hearing you working across them. I think the screens are potentially a great asset but for me at least, I spent most of the time with a video feed of myself, not able to see others and when I did it was out of sync or frozen. "

Everyone agreed the set-up would have been useful during Covid.

They felt there was an advantage to the process and felt there could be a need.

They were impressed with audio quality whilst the network was a negative experience. The video quality was also listed as a negative.

But the main issue was disrupted communication.

So as a summary, the issues could be seen as teething and would surely improve with time.

Message for David J