5G-encode

Final Report

WP3.1.1: 360° Video Streaming VR Assisted Training

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About 5G-Encode

The 5G-ENCODE Project is a £9Million collaborative project aiming to develop clear business cases and value propositions for 5G applications in the manufacturing industry. The project is partially funded by the Department for Digital, Culture, Media, and Sport (DCMS), of the UK government as part of their 5G Testbeds and Trials programme. The project is one of the UK Government's biggest investments in 5G to modernise manufacturing.

The key objective of the 5G-ENCODE project is to demonstrate the value of 5G as part of industrial use case delivery within the composites manufacturing industry. It also is designed to validate the premise that using private 5G networks in conjunction with new business models can deliver better efficiency, productivity, and a range of new services and opportunities that would help the UK lead the development of advanced manufacturing applications.

The project will play a key role in ensuring that UK industry makes the most of the 5G technology and ultimately remains a global leader in the development of robust engineering capabilities when implementing complex composites structures manufacturing processes.

The project will highlight how 5G features such as neutral hosting and network slicing can be applied to transform a private 5G network into a dynamically reconfigurable network able to support a wide range of applications (URLL/eMBB/MMTC) including industrial applications of Augmented Reality/Virtual Reality (AR/VR), asset tracking of time sensitive materials and automated industrial control though IoT monitoring and big data analytics. Such a dynamic network would enable new business models and creation of bespoke virtual networks tailored to specific applications or use cases.

A state-of-the-art test bed was deployed across three sites centred around the National Composites Centre in the Southwest of England. In support of the West of England Combined Authority (WECA) industrial strategy, the NCC plans to keep the test bed as an open access facility for the experimentation and development of new products and services for the composites industry after the completion of the 5G-Encode project. The location and nature of NCC's business would ensure the creation of an industrial 5G ecosystem involving multiple industry sectors and small and medium enterprises (SMEs).

The project consortium, led by Zeetta Networks, brings together leading industrial players (e.g., Siemens, Toshiba, Solvay), a Tier 1 operator (Telefonica), disruptive technology SMEs covering all aspects of network design, deployment, and applications (Zeetta Networks, MatiVision, Plataine), application performance as measured by probes (Accedian), world-leading 5G network research group (High Performance Networks Group in the University of Bristol) and the NCC representing the high value manufacturing industry.

Executive Summary

Training courses with practical elements are typically carried out by trainers either within their training facilities on-site or at a suitable location at the customer site. Both scenarios have economic and environmental costs related to travel, with most being infeasible within the recent COVID-19 climate. Although there are distance learning options, and internet-based courses available, they are limited to webinar style 2D solutions. The use of 5G and more immersive technologies provides a unique opportunity to engage more effectively with the trainer and the practical elements of the training course.

The use case presented within this report evaluates the use of latest 360° video streaming technology, 5G connectivity and VR headgear to demonstrate a fully immersive VR remote learning solution. This solution is used to emulate a physical classroom and allows the user to follow, in real time, the practical course demonstration offered by the NCC in manual composite manufacturing. It relies heavily on 5G's reliable, safe, high bandwidth and low latency connectivity to facilitate uninterrupted high quality two-way communication (3D video and bi-directional audio feeds) between trainer and trainee.

The use case development was split into two testing phases:

The first phase was conducted on 4G LTE and limited to a controlled setting at the NCC with 4 trainees. 50% of the participants indicated that the solution was an enhancement to a conventional course as offered through an online seminar. Poor streaming quality (due to network capability) was stated as the key reason for negative feedback.

The second phase was conducted using the 5G test bed deployed at the NCC. The testing was extended to an external location and opened to a wider testing group of at least 20 trainees. Even with the expanded scope, 91% of the participants indicated that the solution was an enhancement. The 5G testing phase also showed significant advances to the 4G testing by exceeding 700 megabits per second download speed and around 3 milliseconds latency which significantly improved viewing quality and therefore participant engagement and satisfaction.

The immersive technologies tested in this report are shown to be an effective option for distance learning but only when paired with a reliable, high-performance network as offered by 5G technology.

Further technology development and experimentation are required to ensure solution robustness for application outside of the trial, especially VR hardware development, as direct connectivity to 5G is not yet possible. For wider-scale adoption of the technology, access to operational public or private 5G networks will be a prerequisite.

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Abbreviations

2D	*Two-dimensional*
3D	*Three-dimensional*
3G	*Third Generation Mobile Network*
4G LTE	*Fourth Generation Long-Term Evolution Mobile Network*
5G	*Fifth Generation Mobile Network*
AP	*Access Point*
APC	*Automated Preforming Cell*
AR	*Augmented Reality*
CPE	*Customer Premises Equipment*
DCMS	*Department for Digital, Culture, Media, and Sport*
DL	*Downlink*
eMBB	*Enhanced Mobile Broadband*
IoT	*Internet of Things*
IP	*Internet Protocol*
Kbps	*Kilobits Per Second*
KPIs	*Key Performance Indicators*
LRI	*Liquid Resin Infusion*
Mbps	*Megabits Per Second*
MEC	*Multi-Access Edge Computing*
MMTC	*Massive Machine-Type Communications*
NCC	*National Composites Centre*
NCC HQ	*National Composites Centre Headquarters*
NCCi	*National Composites Centre – Filton Site*
NR	*New Radio*
NTP	*Network Timing Protocol*
OS	*Operating System*

P2P	*Peer-to-Peer*
PTP	*Precision Timing Protocol*
RAN	*Radio Access Network*
RTMP	*Real-Time Messaging Protocol*
SA	*Standalone*
SMEs	*Small and Medium-Sized Enterprises*
UEs	*User Equipment*
UL	*Uplink*
UoB	*University of Bristol*
UPF	*User Plane Function*
URLL	*Ultra-Reliable Low Latency*
VMs	*Virtual Machines*
VPN	*Virtual Private Network*
VR	*Virtual Reality*
WECA	*West of England Combined Authority*

1. Introduction

Effective knowledge transfer through training is a core part of people development and is essential for social sustainability. Classroom and workshop training where all attendees are co-located within the same demonstration space are a proven method to facilitate this.

Traditionally, such training courses with practical elements provided by the NCC to customers across the UK have been carried out by trainers either within its training facilities on-site or at a suitable location at the customer site. However, both scenarios can be linked to significant economic and environmental costs due to travel, accommodation, and transportation of equipment. As such, with the continuous drive for sustainability over the past two decades the work developing alternative solutions has become more and more vital.

Additionally, the recent COVID-19 pandemic put extra pressure on training providers and on companies in need of training. This was due to the stringent restrictions put in place such as barring all non-essential travel and gatherings for a significant period.

Though there are distance learning options, and internet-based courses available, the capability to engage effectively with the trainer and demonstrate practical aspects of a course in an immersive way is difficult. As such, more solutions need to be proposed to address this industry challenge.

The VR immersive training demonstrator that is presented in this report will highlight the latest 360° video streaming as an example of an advanced distance learning solution. Demonstration of practical training for the manual lay-up of carbon composite materials, an 'Introduction to Composites' manufacturing training module offered by the NCC, was selected as an example use case.

The solution aims to exploit the capabilities of the 5G technology available to provide distant learning trainees with a real-world experience similar to when on site with the trainer.

1.1 VR Project Objectives

The main project objective was to apply the 360° video streaming VR technology over a fully functional 5G network to improve user experience and training performance from an interactive remote learning solution. The technology was designed to emulate a physical classroom or workshop without the need for the trainers and trainees being physically in the same space.

The use case was created to fill the gap for immersive remote learning solutions. This is particularly pertinent in current times due to the COVID-19 pandemic and sustainability drivers as outlined above. Additionally, this demonstrator can create a work package which has wider implementations in the manufacturing industry for more immersive demonstrations remotely in a variety of scenarios.

One opportunity from a working VR demonstrator is the ability to cascade the digitalisation methodology into other similar courses within the composite manufacturing industry. However, there is also the possibly of applying this more widely within the manufacturing sector as well as outside, as there are various practical courses which could benefit.

The potential benefits for companies of all sizes across the UK as a result of this are numerous. These include:

- Drastic reduction in costs for supplementary activities such as travel, accommodation, and transport.
- Sizeable decrease in emissions as a result of training activities.
- Overall improvements in workforce ability and skill due to more effective training.

1.2 Purpose of 5G in VR Assisted Training

In order to create a comprehensive remote learning experience and achieve an equivalent knowledge transfer as with traditional on-site courses, the internet and any associated internet connection must have sufficient bandwidth to service network traffic created as a result of running an on-line experience.

5G realises this without the need for a wired connection as its radio performance, capacity and flexibility capabilities significantly differ from its predecessor, 4G and conventional Wi-Fi solutions found in industry.

The proposed 360° video streaming VR solution has several specific requirements for the network connection.

- Achieve an average speed which allows for good video and audio quality to be streamed from the trainer to the trainees in the class.
- Provide sufficient bandwidth to enable streaming to multiple devices as a class of trainees will needs to be a specific, minimum size to justify the associated costs of providing training.
- Ensure latency does not affect the stability of the live stream and cause lagging that degrades the trainee experience and hinder delivery of course.

With average speeds theorised to be at least an order of magnitude greater than 4G LTE, 5G has the potential to show a significant improvement. Further, the use of higher frequency bands that have been less widely used thus far, should allow 5G to drastically increase its available bandwidth. As a result, the number of additional devices that can be connected is theoretically much larger. Finally, depending on the location, usage, and maturity of the 5G network, the latency theoretically predicted ranges from below 2ms to 10ms. This is a sizeable difference to the average results of around 20-40ms from 4G LTE, though this can go up to 200ms.

Therefore, it is possible to see that 5G offers significant improvements in all three parameters from the previous generation network and those are the biggest justifications for its use in this work package.

1.3 Use Case Overview and Solution Architecture

The conventional 'Introduction to Composites' practical training course begins with a live demonstration from the trainer on the manual lay-up of a simple flat piece in the form of a coaster using pre-impregnated composite materials.

Trainees then have the chance to try the process for themselves, and though the final product shape is not overly complex, carrying out the process correctly and safely is not a simple exercise. Consequently, the trainer's experience enables a run-through of all the steps in around 45 to 50 minutes, with an expected time allowance for trainees of at least two to four times longer. The process, itself, includes details about working with the different materials and using specific tools alongside theoretical explanations from the trainer which make the visual and auditory cues crucial to satisfactory learning.

The suggested 360° video streaming VR teaching course only focuses on the trainer demonstration section. This is delivered by creating a live broadcast of the practical demo using a 360° camera. VR adds the immersivity for the trainees in the experience and aids with understanding the practical skills shown by having the ability to adjust camera angle and view of the demonstration. Supplementary media is also planned within the VR view in the form of drawings or graphics to improve understanding and knowledge transfer.

Extra functionality also allows for the collaborative training aspect through real time two-way communication, to an instructor offering extra support to trainees and an enhancement of the learning experience as a whole.

Figure 1 below shows the fundamental architecture of the proposed VR solution. The streaming setup is located and controlled from the NCC Headquarters (HQ), while the trainees are based in a remote location with the required hardware.

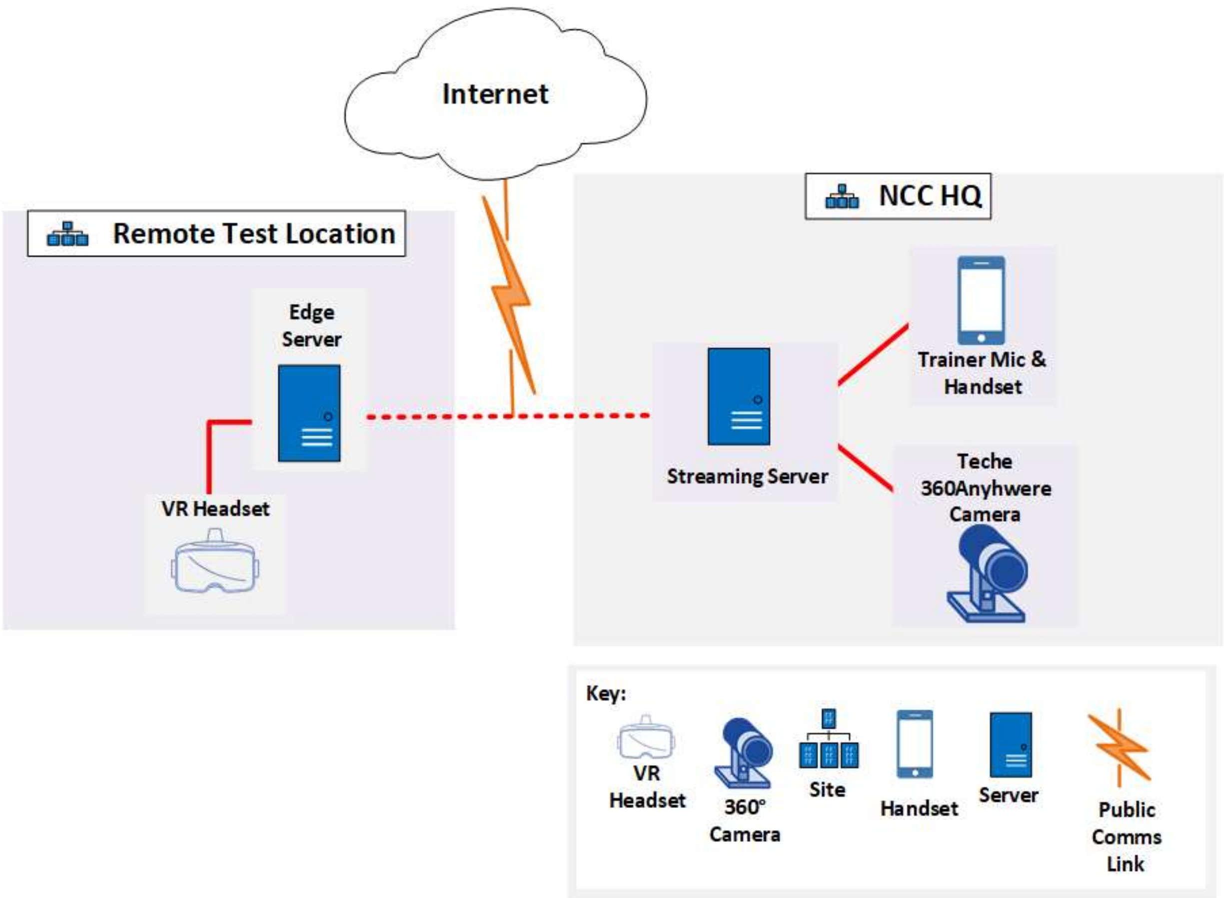

Figure 1 – Fundamental use case architecture

As outlined earlier, in Section 1.2, the use case requires the uplink aspects of the 5G network to be sufficient to support the camera data stream. This is needed to ensure the required quality is maintained throughout the demonstration and there are no gaps in the training.

In order to satisfy all the recognised requirements and overcome any digitisation challenges, MatiVision, an immersive technologies expert company was consulted for support in this use case. Based on their experience, it was possible to integrate the digital features directly and quickly into the solution. From the initial discussions, plans were made to produce the media content required with support from the NCC staff and MatiVision could begin work on the streaming platform which includes two-way communication channels.

1.4 Use Case and Network Metrics

In order to be able to quantify and recognise whether the objectives have been met, two sub-categories have been introduced:

1. Use case monitoring
2. Test bed monitoring

The first sub-category encompasses the user experience of the 360° video streaming VR course and is measured through user feedback. The main points of the feedback are whether the user considers the solution an immersive enhancement on currently available online courses such as a webinar and based on a one-to-five satisfaction grading, rank the experience.

The second sub-category measures the network performance using a selection of metrics collected from the radio network.

Tables 1 and 2 below define all of the measurable quantities for the use case and the test bed, respectively. These are taken from the 'Benefits Realisation' document which contains all requirements defined by the project partners and sponsors at the project inception.

Table 1 – Use case monitoring measurable quantities

Use case metric	Target audience	Measurement type	Unit of measurement
Alternative VR course is an immersive enhancement to conventional webinar courses	Uptake by NCC (and industrial partners)	Feedback from survey after course	Yes / No
Alternative VR course is an immersive enhancement to conventional webinar courses	Uptake by academic institutions	Feedback from survey after course	Yes / No
Quality of 360° live stream experience	All	Feedback from survey after course	1 – 5 Grading* (1 = Extremely dissatisfied, 5 = Extremely satisfied)

* Note – need to score 4 or above to class as a high score.

Table 2 – Testbed monitoring measurable quantities

Network metric	Counter	Description	Unit of measurement
Camera to server bandwidth	Total uplink IP throughput	Total uplink throughput	Kilobits per second
Server to user bandwidth	Total downlink IP throughput	Total downlink throughput (all users)	Kilobits per second
Server to user bandwidth	Total downlink IP throughput	Total downlink throughput (each user)	Kilobits per second
Latency tolerance	E-RAB level IP latency in downlink	Mean IP latency in downlink at the E-RAB level	Milliseconds
Jitter tolerance	NTP mean jitter	Mean value of the jitter estimator between AP and NTP servers averaged over granularity period	Milliseconds
Packet loss tolerance	Downlink PDCP SDU air-interface loss rate	Fraction of IP packets (PDCP SDUs) which are lost on downlink interface	Percentage
Packet drop – downlink	Downlink PDCP SDU drop rate	Fraction of IP packets which are dropped on the downlink	Percentage

Packet drop – uplink	Uplink PDCP SDU drop rate	Fraction of IP packets which are dropped on the uplink	Percentage

1.5 System Requirements and Selection

As described in Section 1.3, the proposed solution is aimed at providing a comprehensive immersive remote learning course which has thus far been difficult at the NCC. This has been the case because of the need to capture the required level of detail in real time with the ability to broadcast it directly to the interested parties.

However, with recent advancements in video recording hardware and software this difficulty is alleviated and there are cameras able to capture all 360° of a relevant space with high quality. An example of this is the TECHE 360Anywhere camera that is capable of live streaming up to 8K video quality. The up-front camera unit cost is high, but this is due to the specific composite manufacturing requirements detailed further in Section 2.3. This can be combined with a comparatively inexpensive clip-on microphone to provide all the additional specialised equipment for the course trainer.

On the user side, to get the full benefit of the 360° video, a VR headset provides the complete package. The Oculus Go headset delivers the necessary functionality, video quality and two-way audio integration for the use case. It is a more cost-effective item than some of the more advanced headsets on the market which have increased functionality and better graphics options. Additional handheld mobile devices can also be used as a backup when accessing the remote course, though these do not provide the fully immersive experience of the headset.

In terms of the stream transmission between the trainer and the trainee the system relies on peer-to-peer (P2P) streaming to keep the latency down to a minimum. A P2P channel is opened between every device. For the video, a P2P channel is opened between the device and the streaming server. For the trainer communication a direct channel is opened between the two devices with only audio streaming enabled so the trainer and trainee can speak to each other in low latency. For the video streaming a mid-range hosting environment is required which can be scaled up for more concurrent users or classes. For the audio streaming the P2P channel is between the two devices, meaning that the server is only used to relay messaging and the actual streaming takes place between the devices themselves. This keeps the hosting requirements to a minimum.

1.5.1 Project Methodology

To gauge the performance improvements of a 5G network and understand the capabilities of an already proven and tested network, the use case testing was split into two testing phases:

- Phase 1 – implement a 4G LTE network architecture to capture baseline data of the performance of the setup.
- Phase 2 – implement a 5G network architecture to test the capabilities of the newer technology and make an analysis of performance when compared with the 4G technology.

The Phase 1 results and discussions were presented in an earlier report but will be briefly summarised within this report for completeness and ease of reference.

Sections 2.4.1 and 2.4.2 describe the approach for delivering each phase of the use case.
Sections 2.5.1 and 2.5.2 detail the relevant phase results and discussion.
Sections 3.1.2 and 3.1.3 document previous 4G network testing results and outcomes.
Sections 3.1.5 and 3.1.6 present 5G network testing results and outcomes.

2. Use Case Development and Investigation

2.1 Use Case Architecture

The system setup of the use case was split across two locations:

1. NCC Headquarters (HQ)
2. Remote test location

The equipment and connections within the NCC HQ side did not change through both Phase 1 and 2. These included the TECHE 360Anywhere 360° video camera and a mobile device which the trainer used to control of the media content on the video stream. The mobile device was connected wirelessly to a 4G small cell in Phase 1 and 5G small cell in Phase 2, while the 360° camera used a wired connection.

The live video stream from the camera was transmitted to a streaming server via a wired network connection. The streaming server managed the live video feed and transmitted it to a caching server which received the live video stream in a one-to-one relationship and managed the calls to view overlays on the video stream. The most main differences between the two testing phases related to the remote test location side of the setup and will be described in further detail in Sections 2.1.1 and 2.1.2.

2.1.1 Phase 1 – 4G LTE Architecture

Phase 1 – 4G LTE used two sites: NCC HQ and a remote test location at NCC, Filton called NCCi. NCCi is located around 5 miles away from NCC HQ. The specific hardware used for the trials at NCCi included two Oculus Go VR headsets alongside two handset devices and a master control device. A 4G small cell provided the 4G connection and transmitted the video streaming data from the caching server to the handset devices, the master control device, and a customer premises equipment (CPE) device which produced a Wi-Fi connection to the VR headsets. Figure 2 below combines and visually summarises the architecture described in Section 2.1 and 2.1.1.

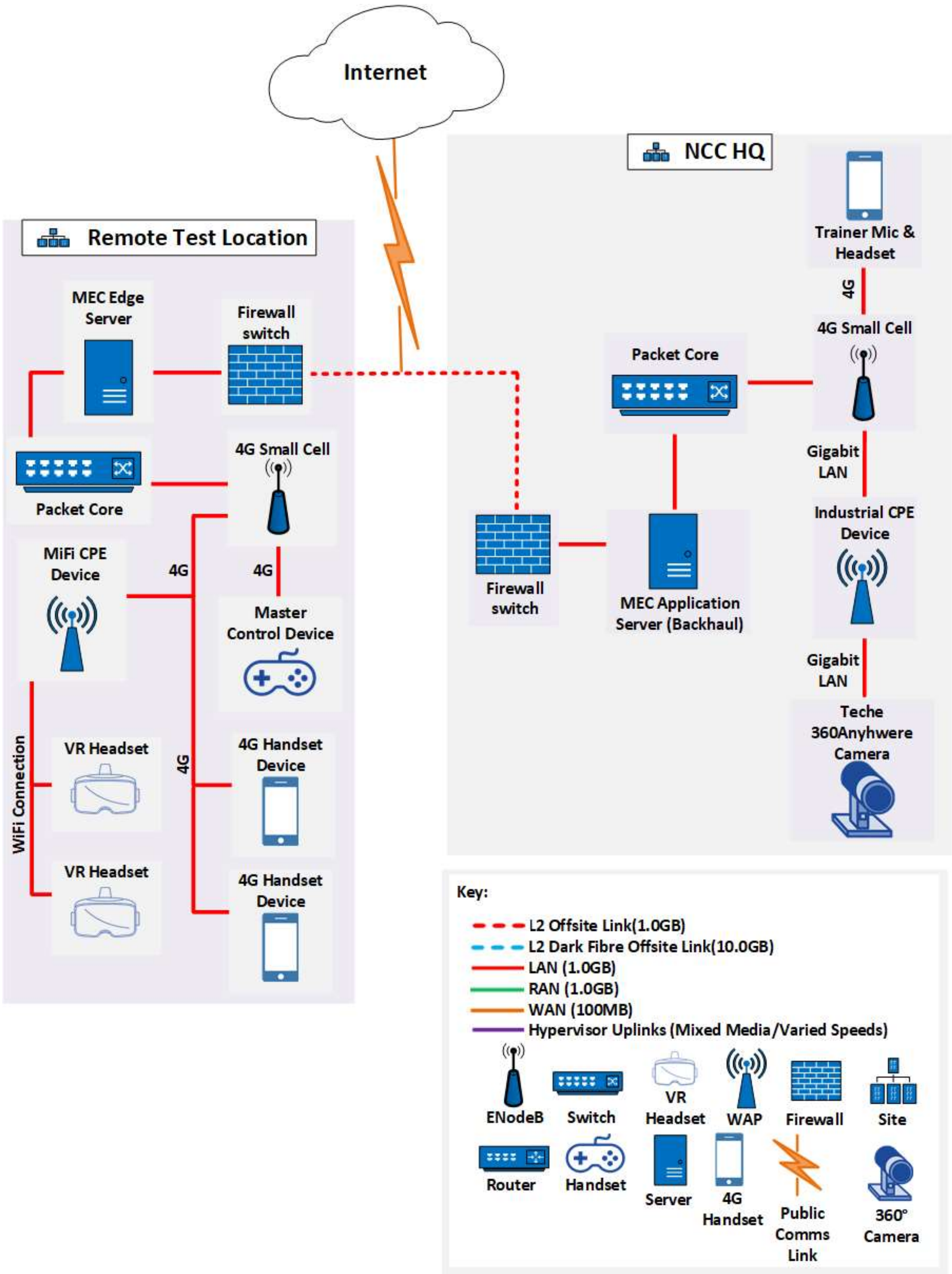

Figure 2 – Phase 1 - 4G LTE trials architecture map

2.1.2 Phase 2 – 5G Architecture

Phase 2 – 5G trials used NCC and a location in Millennium Square, Bristol; located approximately 8 miles from one another. The hardware for the trial increased to five Oculus Go VR headsets, three handset devices and a master control device. The VR headsets and handset devices were split between two CPE devices and connected over Wi-Fi while the CPEs were linked to a 5G small cell over a Nokia 5G connection. Figure 3 below combines and visually summarises the architecture described in Sections 2.1 and 2.1.2.

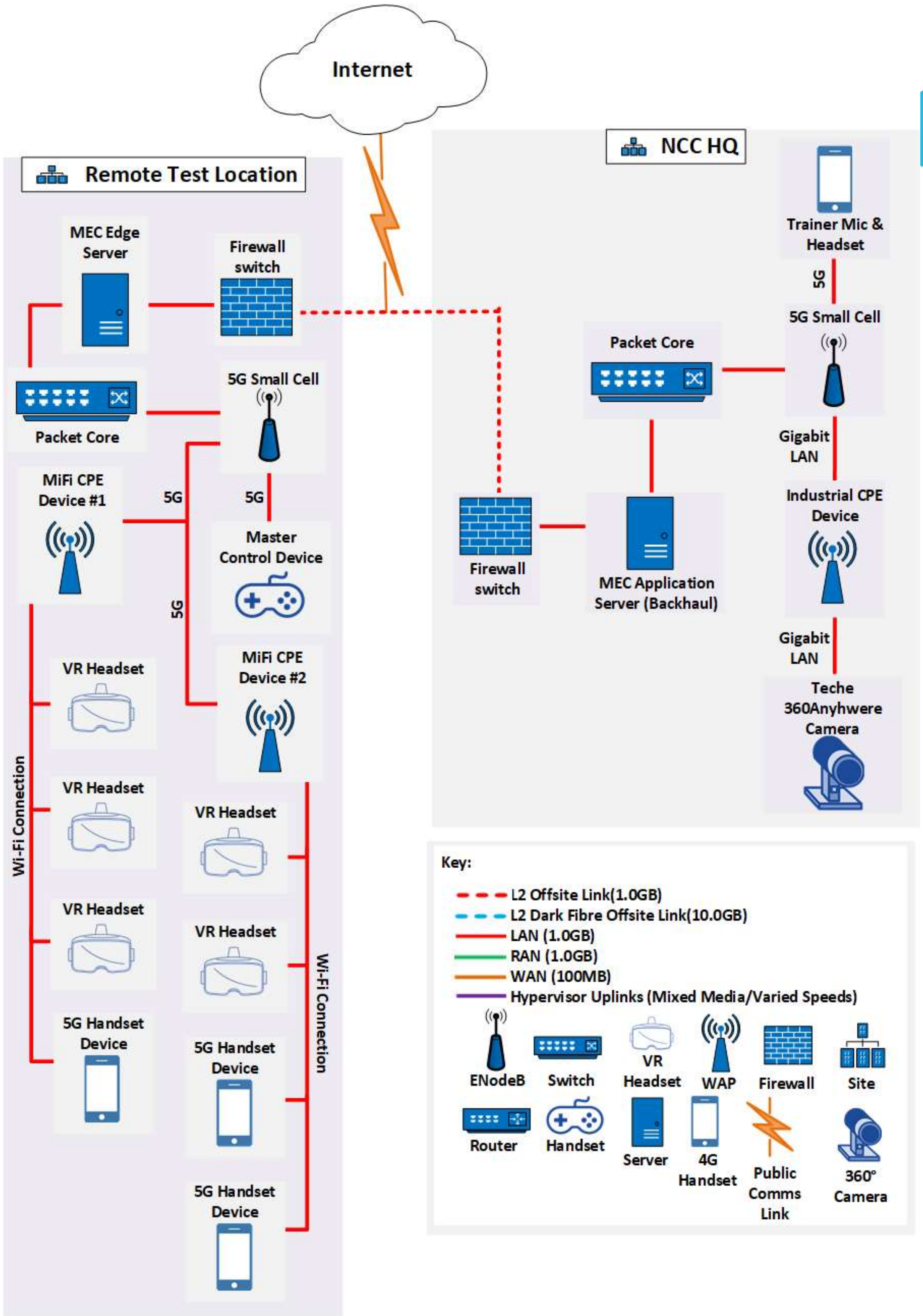

Figure 3 – Phase 2 - 5G trials architecture map

2.2 Use Case and Network Benefits

With a successful outcome from the project the use case will offer significant benefits for similarly positioned work packages that can implement 360° video streaming VR technology and a 5G network.

2.2.1 Use Case Benefits

Being able to effectively digitise practical training courses unlocks a range of similar use cases across a variety of industry sectors not limited to manufacturing.

This will be significant in the development of remote working packages and will improve the training outreach throughout the UK. A functional VR solution will reduce the need for travel, accommodation, and transport of equipment to and from provider and customer sites. This will be crucial in decreasing the overall financial as well as environmental costs associated with these services. As a result, the products will experience long-term cost reductions that will make them more affordable to SMEs.

As mentioned above an effective remote working solution such as this one will contribute to the overall environmental sustainability goal of enterprises such as the NCC by using less energy in a more efficient capacity. This will lead to a sizeable carbon footprint reduction that will be a further contributing factor. In time these benefits will be able to cascade down into the wider manufacturing and advanced engineering fields and have a greater effect on the UK net zero strategy overall.

The use case can also have social sustainability benefits as well. A matured solution has the potential of improving the training experience and knowledge transfer to the trainees and thus producing a more skilful workforce.

2.2.2 Network Benefits

Based on the predicted capabilities of a 5G network, the use case can specifically benefit from the lower latency, the higher bandwidth, and faster average speeds.

The wider bandwidth available in 5G will enable a much larger amount of data to be transferred from one location to another at any one time by single and multiple devices. As such, larger cohorts of trainees per course are achievable or, alternatively, enhanced quality of video and audio for a smaller cohort. For other use cases this can aid large amounts of data acquisition and transfer from various sensors to a processing unit. This is crucial in the automated pre-forming cell (APC) end effector upgrade use case within the 5G-Encode project and more details can be found regarding this in that final report.

The shorter latency of 5G allows for real-time communication with the trainer which can improve the trainee experience and understanding. The lower latency can also improve the capabilities of time sensitive signals such as those in precision machine control applications. This is pertinent in the liquid resin infusion (LRI) use case within the 5G-Encode project and more details can be found regarding this in that final report.

The speed itself will improve the video and audio quality achievable by the stream to the trainees. Additionally, for other use cases it can increase efficiency due to a better productivity overall. This will specifically aid the asset tracking use case within the 5G-Encode project and more details can be found regarding this in that final report.

2.3 Use Case Decisions and Developments

In order to ensure that the hardware presented throughout Section 1.6 and the ancillary software work effectively for the specific use case, certain decisions and developments had to be made over the project timeline. These were as follows:

- 360° camera protection rating:
  The TECHE 360Anywhere camera is rated at IP66 which combines the highest dust protection with a very high protection against water ingress. This was necessary because composite materials manufacturing processes may sometimes release fine carbon dust particles which can be harmful to any electrical equipment.

- <u>360° camera cooling system:</u>

  The TECHE 360Anywhere camera uses a passive heatsink instead of a fan as part of its cooling system. This is a feature that falls under the IP66 rating and as such has a reduced chance of any carbon dust being taken into the camera internals and damaging the equipment.

- <u>Streaming server industrial compatibility:</u>

  For the streaming functionality, a custom application was created that supports ingest via a real-time messaging protocol (RTMP) from the 360° video camera. This is converted to a low latency streaming protocol and a connection is established between the streaming server and a device.

- <u>HTML5 player application:</u>

  A custom HTML5 application was developed with low latency streaming capabilities for video and the custom streaming application. The application also implements the low latency audio streaming between trainer and trainee devices.

- <u>Handset operating system (OS):</u>

  The handsets that could be used as a backup for the VR experience or as supporting equipment were limited to solely Android OS devices. This was due to the safety protocols included in the Apple iOS which would not allow stand-alone licenced software/servers and would only trust ones with public licences.

- <u>VR headset functionality:</u>

  The chosen VR headsets – Oculus Go, are a more cost-effective headset with slightly less functionality than the latest devices available, e.g., only 3 degrees of freedom rather than 6. However, this is somewhat advantageous for the use case in question because the only necessity is the access to the stream and the headset audio integration. Additional capabilities only introduce extra setup steps which could lead to technical difficulties during the training course. Unfortunately, as all VR headsets currently are for the leisure consumers it is not possible to fully restrict them for the proposed industrial application.

- <u>Course trainer setup:</u>

  For the use case proof of concept stage, it was found to be useful to have two members of staff on the trainer side. This was so there would always be someone to support the trainer with the streaming setup and broadcast. However, with more practice and experience it may be possible for the trainer to facilitate the entire process and make it more resource efficient overall.

2.4 Use Case Testing

In both Phase 1 and Phase 2 the testing programme was the same. A demonstration was carried out by the NCC trainer live and broadcasted to several devices. The number of devices differed based on the network capabilities and the location of the trainees changed between as outlined earlier in the report. Further details and the results of the trials are presented in the following sections.

2.4.1 Phase 1 – 4G LTE

As described in Section 2.1.1 the Phase 1 trials were carried out within the available NCC premises between the HQ and the NCCi site at Filton. The trainer setup for the course demonstration at NCC HQ is shown below in Figure 4.

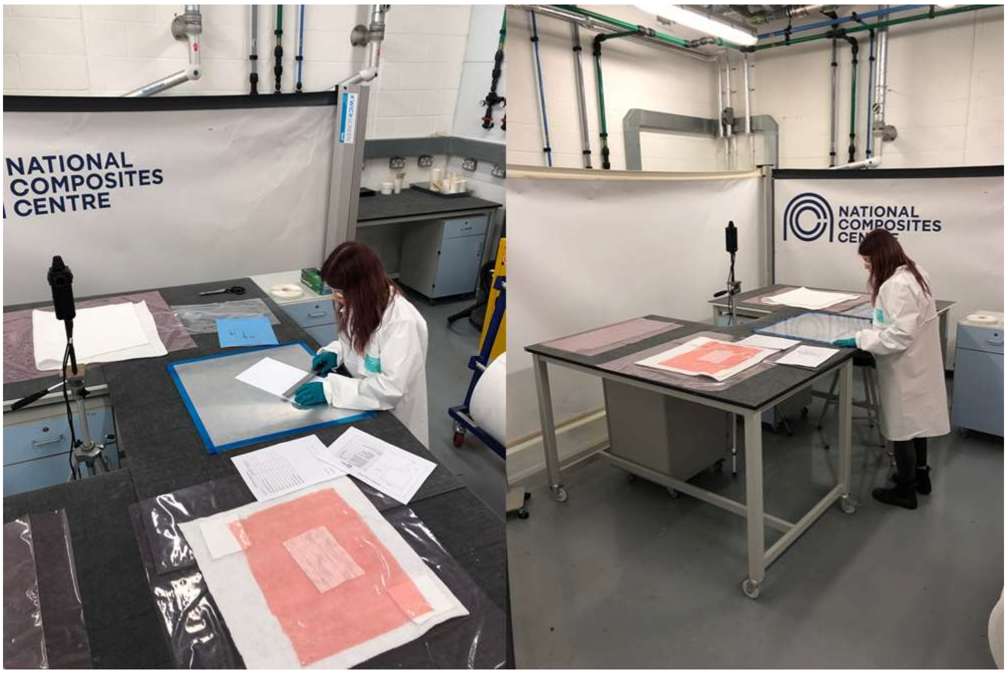

Figure 4 – Phase 1 trainer setup for course demonstration

During the initial Phase 1 tests the attempt was to create a mobile data access point on a Samsung 4G handset and tether the VR headset to that. However, this was not achieved due to difficulties with the VR tethering and the test users during those trials were only able to observe directly using the mobile handsets. This meant the experience immersion was limited but it was useful to test out the streaming server settings and setup. Figure 5 below shows the trainees watching the training course demonstration live on the mobile devices.

Figure 5 – Phase 1 trainees watching training course demonstration on mobile devices

A second test was organised for Phase 1 during which the VR headsets were connected to a CPE device over Wi-Fi as shown in Figure 2 while the CPE itself has a 4G connection to a small cell. This was effective and allowed the immersive stream to be viewable within the headsets. Figure 6 below shows the trainees using the VR headsets.

Figure 6 – Phase 1 trainees watching training course demonstration on VR headsets

The user feedback from the Phase 1 trials was consistent across the two sessions described above. Figure 7 below presents the results regarding the satisfaction of the trainees with the live stream experience, while Figure 8 shows how many would use VR instead of on-site training. The total number of trainees in the data was four.

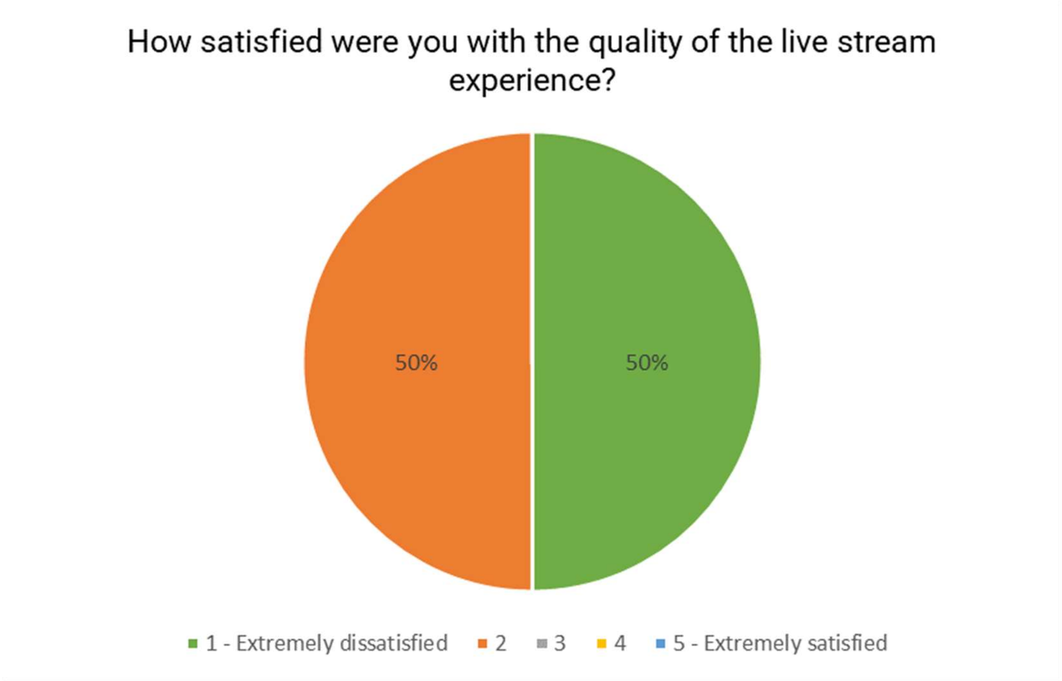

Figure 7 – Phase 1 user feedback regarding satisfaction with live stream experience

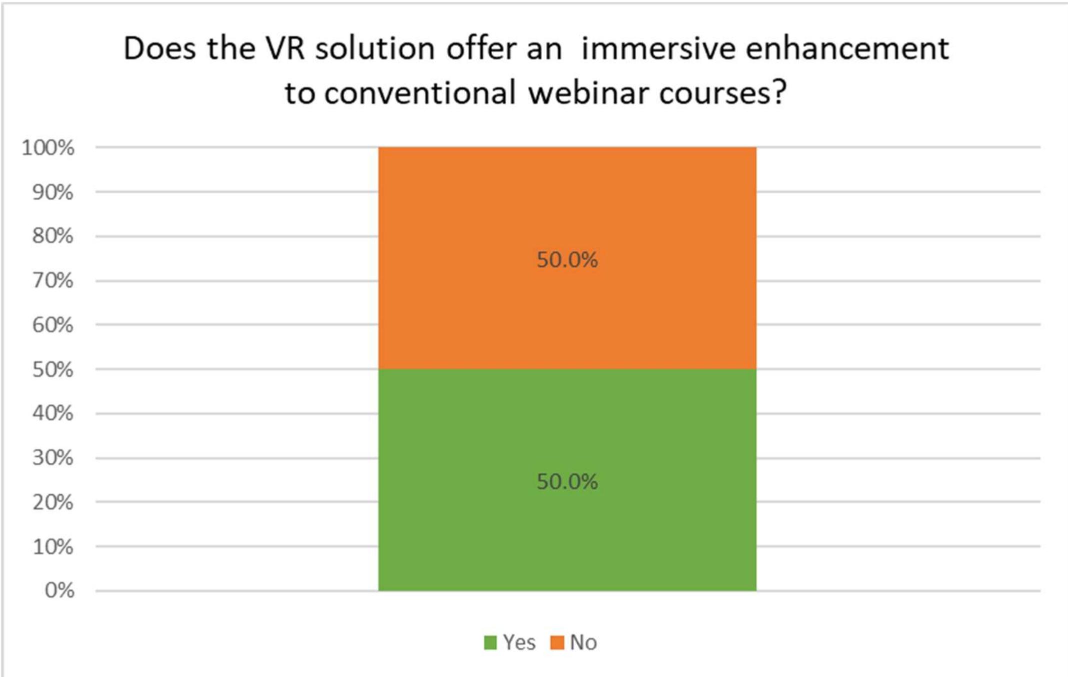

Figure 8 – Phase 1 user feedback regarding the enhancement of the VR solution over a conventional webinar course

The feedback forms included more questions to aid the understanding and development of the use case which were detailed in the previous case study report and thus will not be repeated here. The results from these have been included in Appendix A.

2.4.2 Phase 2 – 5G

The Phase 2 trials as outlined in Section 2.1.2 were carried out on Millennium Square in the Bristol City Centre as part of a two-day continuous demonstration made up of four separate user sessions. The number of devices that were run simultaneously was increased, however the trainer setup at NCC HQ was similar to that used in Phase 1 as it was found to be working, as necessary. This is shown in Figure 9 below.

Figure 9 – Phase 2 trainer setup for course demonstration

The trial setup itself consisted of five workstations and this is shown below in Figure 10.

Figure 10 – Phase 2 trial setup on Millennium Square, Bristol

For the Phase 2 trial the VR headsets were once again connected via Wi-Fi to CPE devices as outlined in Figure 3 which in turn were connected to a small cell through 5G. This way of connecting the VR devices proved to be more robust than attempting to tether to mobile devices which were themselves connected through 5G and as a result the workstations in all test sessions could be filled, as shown in Figure 11 below.

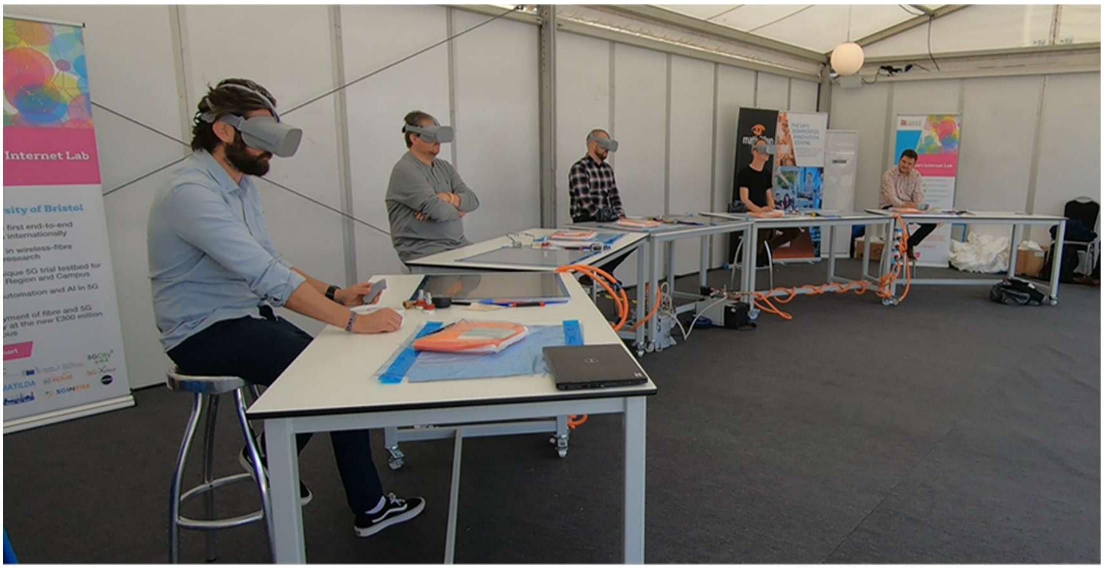

Figure 11 – Phase 2 VR session with all workstations occupied

Over the course of the demonstrations, it was possible to record more footage of the VR experience as captured by the 360° camera and viewed by the trainees through the headsets. Snapshots of these are shown in Figures 12 and 13, respectively.

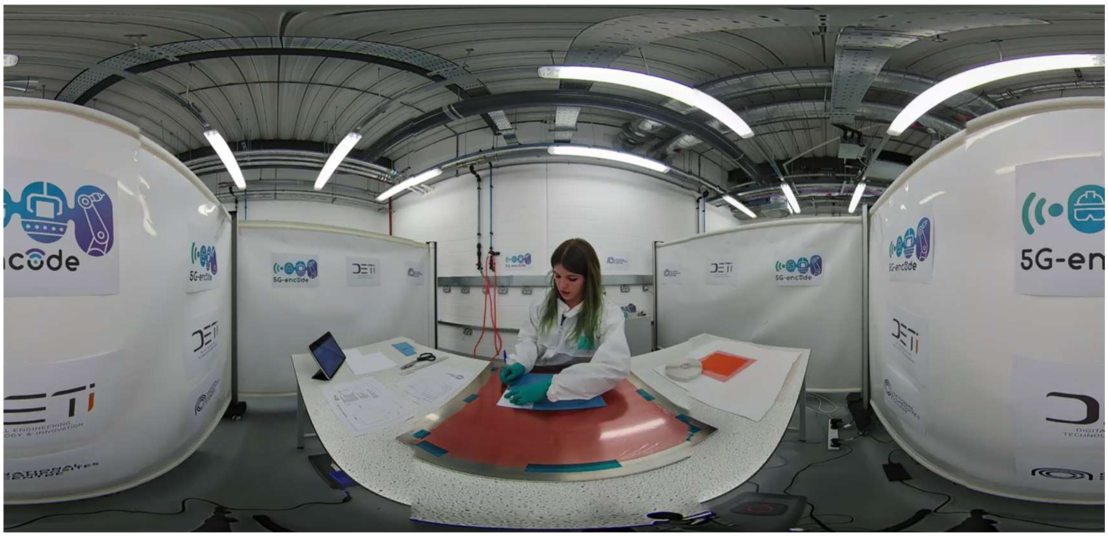

Figure 12 – Phase 2 view from 360° camera

Figure 13 – Phase 2 field of view of VR user

As part of the Phase 2 trial, additional graphics were included within the 360° video stream that would aid the trainees with understanding the technical drawings and paperwork required for the training course demonstration. This has been shown in Figure 14 below.

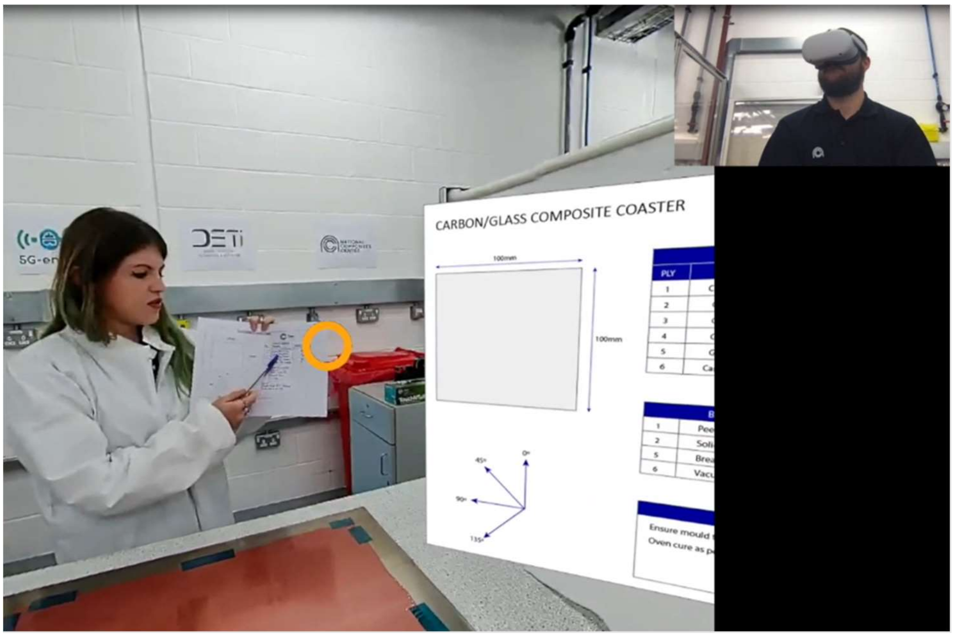

Figure 14 – Phase 2 additional graphics displayed with 360° video stream

Similarly, to Phase 1, user feedback was collected from all of the VR sessions within the Phase 2 demonstrations and upwards of 20 sets were collected which resulted in a more comprehensive view of the experience. Figure 16 shows the latest results on the satisfaction of the users with the VR experience, while Figure 16 presents the percentage of users who would use VR over on-site training.

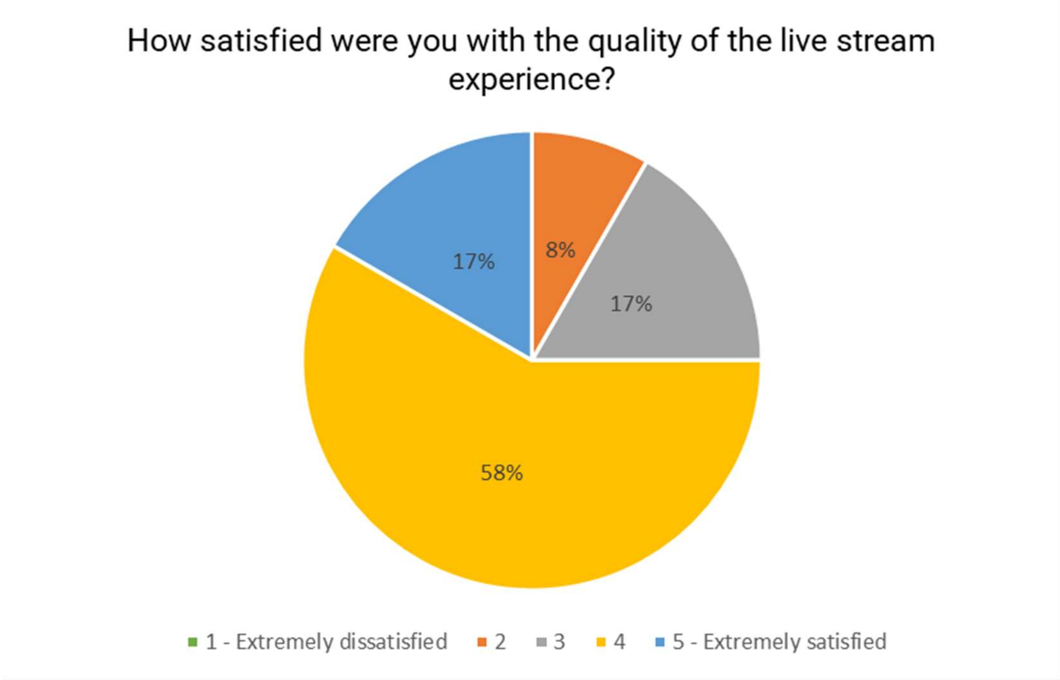

Figure 15 – Phase 2 user feedback regarding satisfaction with live stream experience

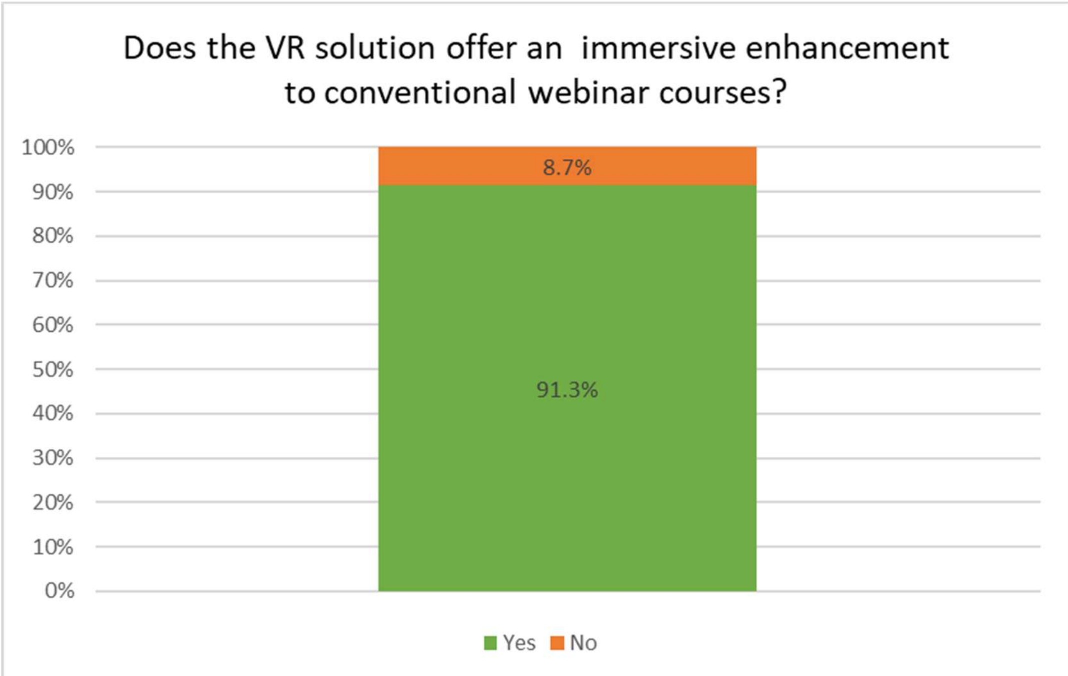

Figure 16 – Phase 2 user feedback regarding the enhancement of the VR solution over a conventional webinar course

Further user feedback from the Phase 2 VR trials has been presented in Appendix B.

2.5 Use Case Discussion

2.5.1 Phase 1 – 4G LTE

From the results of the user feedback presented in Figures 7 and 8 as well as the additional figures in Appendix A it was clear that the experience in the 4G trials was not of a satisfactory level. This can be explained by the screenshots taken of the video stream from the trials, which have been reproduced in Figure 17 below.

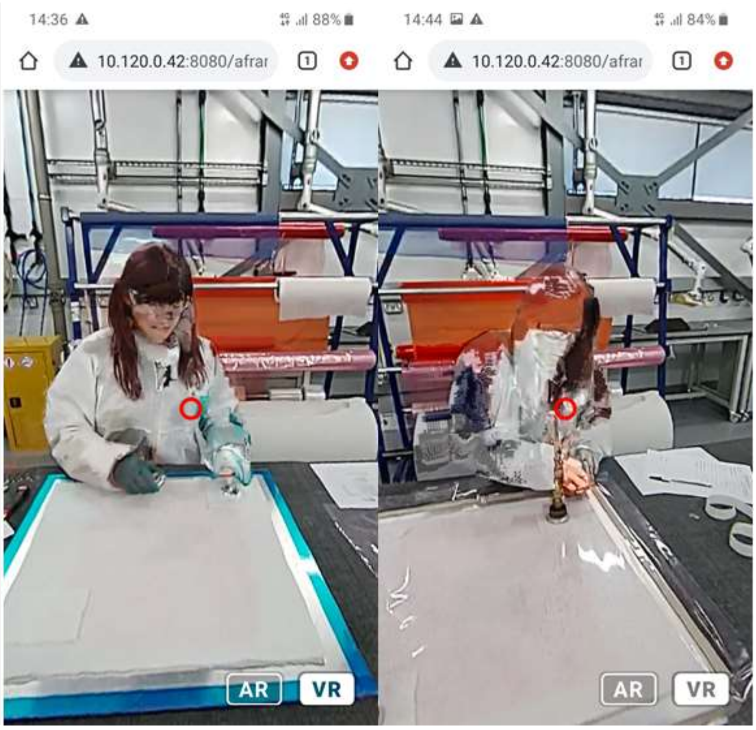

Figure 17 – Phase 1 video stream quality

Deficient performance of the network resulted in limitations in the picture quality (interpreted as elevated levels of latency) and that negatively affected the users' experience, the knowledge transfer efficiency, and the communication with the trainer. Additional graphics to support user engagement were also not possible in Phase 1 tests as it would severely impact the quality and reliability of the video stream.

As such, unfortunately, the benefits expected from the use case could not be fully experienced in Phase 1. However, the potential and the novelty features of the service were acknowledged by the users, which suggested when the network performs better with the 5G technology and the service is more stable and robust, then the experience will likely have a different impact.

One lesson learnt from this trial was regarding the connectivity of the Oculus Go VR headsets to the network. Since the headsets are not directly able to connect to the 4G network it is necessary to have an intermediary device such as a CPE to provide Wi-Fi from a 4G connection. This could then be applied to the Phase 2 trial to reduce the troubleshooting time and make the time used more efficient.

2.5.2 Phase 2 – 5G

Using the 5G connection, visual improvements were experienced in the video quality as seen in Figures 12 to 14. As such, the issues with a degraded quality video stream as seen in Figure 17 were resolved.

This is further supported by the results from the user feedback presented in Figures 15 and 16, as well as the additional ones in Appendix B. Specifically, 75% of the users who attended the VR sessions were very satisfied with the experience and gave high scores of 4 and above. While over 91% of all users would choose the VR training over the conventional on-site training in the future based on their experience. As per the project objectives, data was recorded separately for this statistic depending on uptake – i.e., industrial, or academic. This total percentage was made up of around 82% positive response from the industrial users and almost 100% from the users with an academic background.

Furthermore, 65% of users stated sufficient to high level of knowledge transfer obtained by the VR course. This was qualitatively supported by the users on Millennium Square during the AR training course in WP3.1.3, where comments were made on the benefits of having the VR teaching demonstrator prior. Finally, 17 of the users identified the technology as immersive and captivating which is extremely promising and clearly works towards reaching the overarching objective for the use case.

Even with these optimistic findings, the demonstration was extremely useful in highlighting several limitations or areas for development. These are as follows:

- Course organisation – This needs to be considered to reduce end user fatigue experienced by several the trainees. This could be done by re-structuring the demonstration to introduce additional question and answers sections or breaks to segment the course.
- Camera type and positioning – Implementing a multi-camera setup which can provide additional vantage points for the trainees to utilise. This can be made up of 360° cameras or combination of fixed cameras. The aim for this is to improve the immersive experience by providing more flexibility for the trainees.
- VR hardware – This was showing its limitation with cooling difficulties over the length of the course. This could potentially be improved by introducing more regular breaks or trialling out different headsets with better cooling systems.

The trial also allowed for several lessons to be learnt and put in the protocols for future demonstration or developments of the use case.

- Workstation design - Providing sufficient workstation space for each user allowing them to naturally space out in the room. This will help reduce any interference that may occur between the VR headsets.
- Trainer camera placement - From the qualitative user feedback, it was found that the 360° camera placement in relation to the trainer workstation is critical. This is because there are areas near the base of the camera where blind spots occur due to the separate lenses stitching together their feeds to form a continuous image. In the future, test runs of the setup prior to the official session can ensure that no information is lost by the local blind spots that occur in the image capture.

One challenge that is outstanding after the latest trials using the 5G architecture is the specific stream configuration implemented in the demonstration. There are two options:

1. Segmented streaming – Transmitting video recording in packets of a few seconds each from streaming server to a caching server where it is collected and then sent out to the relevant viewing devices. Inherent delay of circa 8 seconds is present due to the time taken to collect packets and transfer data from server to device.
2. Low latency streaming – Transmitting data directly from the streaming server to the viewing devices by-passing the segmentation stage. Allows for much lower delays between video capture and viewing feed but may induce jitteriness or lag.

The first option would allow for smooth high-quality streaming at a high bitrate thus improving the user experience. However, the function to communicate with the trainer in real-time will have a diminished effect due to the larger delay introduced.

The second option would allow for full exploitation of the two-way communication between trainer and trainee. But will introduce issues with the bitrate used from the 360° camera and resulting jitter in feed to viewing devices.

2.6 Use Case Conclusions

The use case development outlined within this report presents a significant amount of progress in terms of the performance of the package and the experience achieved for the users. It is recommended that this progress be considered alongside the progress made in the Augmented Reality (AR) use case. A summary of this is included in Appendix C. As a result, the objective of producing an immersive and comprehensive remote learning course through 360° video streaming in VR can be considered completed at this stage. However, the set of trials carried out thus far have identified numerous improvements that can further enhance the course. Additionally, to permit a direct comparison between the conventional training course and the 360° VR one, another trial is required which runs them in series to a control group of trainees.

Nevertheless, from the results presented in Sections 2.4.1 and 2.4.2 it is possible to draw several conclusions. Firstly, the use case proved its viability by enabling a sizeable group of users to proficiently progress through the practical training course remotely. The immersive experience demonstrated that it could transfer knowledge efficiently and this was supported by the user feedback regarding the use of 360° VR courses instead of conventional ones.

The above was made possible by the much greater bandwidth offered by the 5G network which clearly significantly improved the stream quality from the baseline 4G LTE trial. This meant that the trainees of the course could experience a more immersive environment and extract much more from the content as a result. This is supported by the positive user feedback collected from Phase 2 and specifically the proportion of users who were satisfied with the quality of the course and the viewing.

Lastly, the additional functionality of two-way communication within the training course can fulfil all of the requirements for an emulated classroom style scenario. However, this will require further testing once the streaming configuration is finalised as per the discussion in the previous section.

3. 5G industrial Assessment

3.1 4G LTE and 5G Network Testing

As described earlier, to make a reasonable comparison of a 5G against an existing network technology, a trial was run using 4G LTE which acted as a baseline. The use case testing itself was fundamentally the same which ensured the improvements from the different trials could be identified. Apart from the developments within the use case scenario itself, data was recorded from the trials to analyse the network performance also and these will be outlined within the following sections.

3.1.1 4G LTE Test Setup

The 4G LTE system setup was as outlined in Section 2.1.1. There were several networking issues identified during the configuration of the infrastructure which delayed testing:

- Extended time required to configure Dynamic IP addressing on 4G network to allow 360° camera to be assigned an IP address.
- Configuration of Virtual Machine on multi-access edge computing (MEC) server to enable video stream output to reach trainee devices.
- Remote working across a virtual private network (VPN) access point.

As the VR use case requires quite a sizeable portion of the network bandwidth for multiple users, the trial was carried out independently from other use cases i.e., no other use cases were active on the 4G network during execution of the VR use case. This ensured that the available bandwidth was maximised enabling the best possible presentation for the experience as well as ensuring network level statistics captured related to the VR use case.

3.1.2 4G LTE Network Metrics

Network performance was reviewed for the day of the VR Phase 1 trial. The VR demonstration was conducted between 11:30 and 14:00. The ip.access 4G RAN network was configured to accumulate metrics for 60 mins and then send a log at the end of each hour to the log server. This logging characteristic is reflected in the charts presented in this section.

Figure 18 below displays the 'Total Uplink IP Throughput', and this measurement provides the total uplink throughput in kilobits per second (kbps). The uplink throughput in kbps was calculated by dividing the count of the total volume of uplink data received in kbits, by the time taken to receive the data in seconds. The maximum measured uplink throughput and target ranges for this measurand are displayed in Table 3 below.

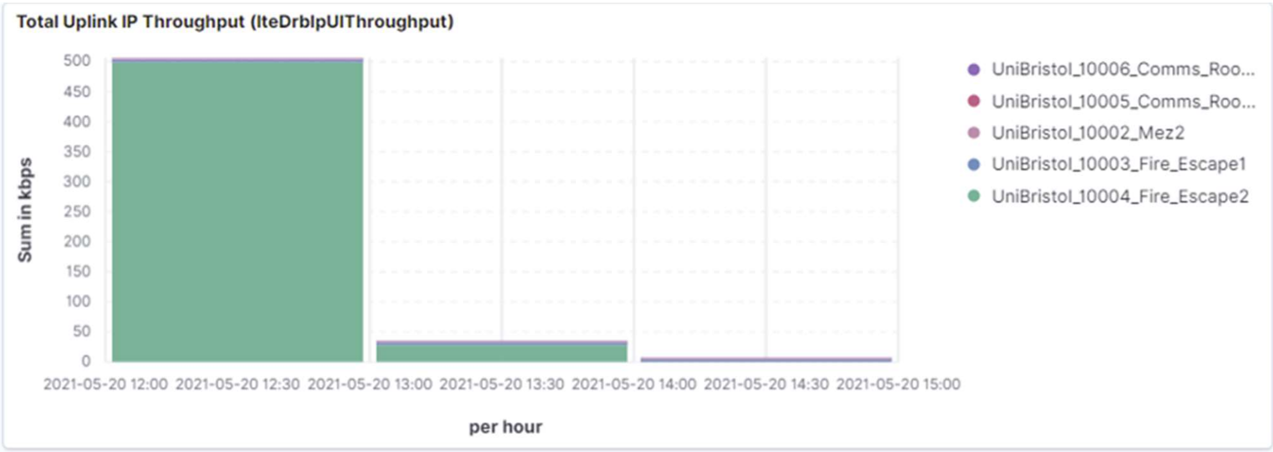

Figure 18 – Phase 1 total uplink IP throughput

Table 3 – Total uplink IP throughput Phase 1 measurement and targets

	Maximum Recorded (kbps)	Phase 1 Target (kbps)	Phase 2 Target (kbps)
Total Uplink IP Throughput	~500	1,000 – 10,000	10,000 - 100, 000

Figure 19 below displays 'Total Downlink IP Throughput', and this measurement provides the total downlink throughput in kbps. The downlink throughput in kbps was calculated by dividing the count of the total volume of downlink data received in kbits, by the time taken to receive the data in seconds. The total measured downlink throughput and target statistics for this measure are displayed in Table 4 below.

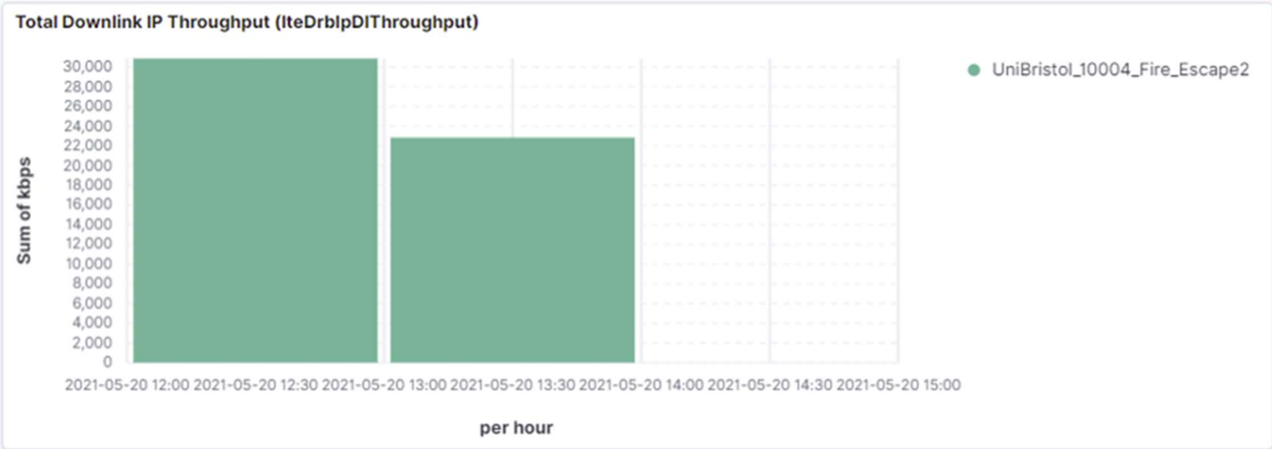

Figure 19 – Phase 1 total downlink IP throughput

Table 4 – Total downlink IP throughput Phase 1 measurement and targets

	Total data throughput recorded between 12:00 and 13:00 (kbps)	Phase 1 Target (kbps)	Phase 2 Target (kbps)
Total Downlink IP Throughput	~30,000	>= 4, 000	>= 20, 000

Figure 20 shows the measure of IP latency in the downlink for each radio unit passing data to support the use case. Latency between devices communicating over the network had a mean of around 8 ms. As such, in the benefits realisation specification, the measured latency is significantly less than stated.

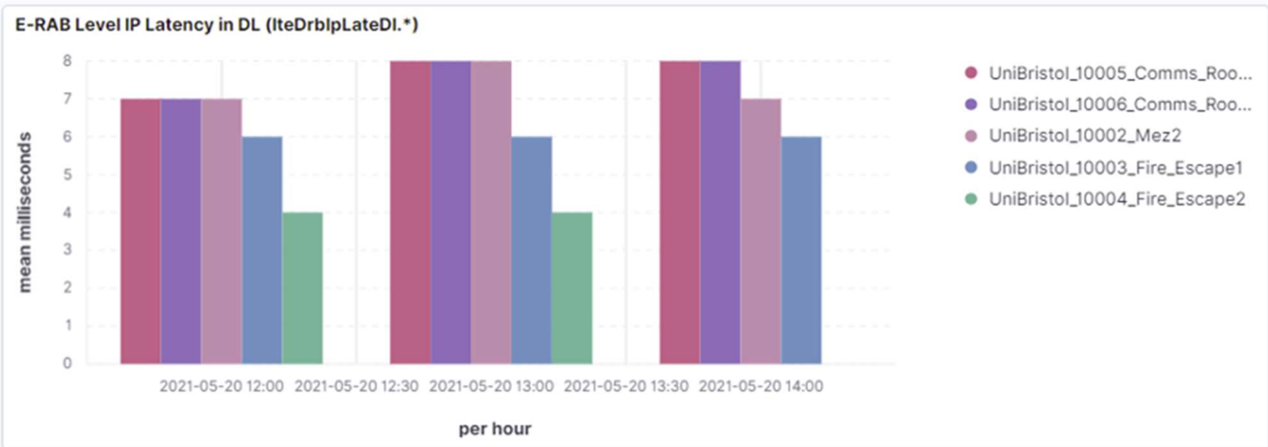

Figure 20 – Phase 1 IP latency downlink

Figure 21 shows mean packet jitter experienced during the use case Phase 1 test. In the benefits realisation specification packet jitter is specified in milliseconds, this relates to measurements possible in a wired network. Referring to Section 2.4.1 in the 4G/5G Network Performance Evaluation Guideline, packet loss and jitter are defined with the following statement:

"The main factors that cause packet loss and jitter are signal quality over the air interface, eNodeB load, and packet loss or jitter on the transport network. Poor air-interface signal quality may increase the packet error rate, which results in more packet retransmissions and segmentation. As a result, the number of lost packets and jitters increases."

Thus, the metric generated was measured in mean packet jitter not milliseconds as documented in the benefits realisation guide.

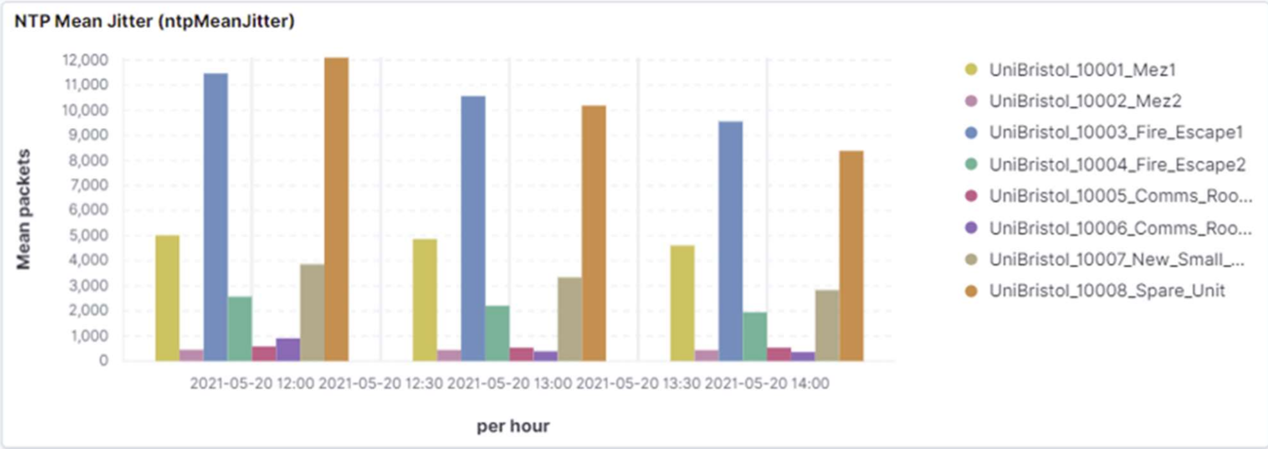

Figure 21 – Phase 1 NTP mean jitter

Additional metrics were also captured from the streaming server application. This was able to monitor the data coming into the server from the 360° camera and data going out of the server to the trainee devices. Figure 22 below shows this data with the orange set representing the camera upload (i.e., 4Mb/s bitrate) and the green set representing the downloads (i.e., a multiple of the bitrate depending on devices connected).

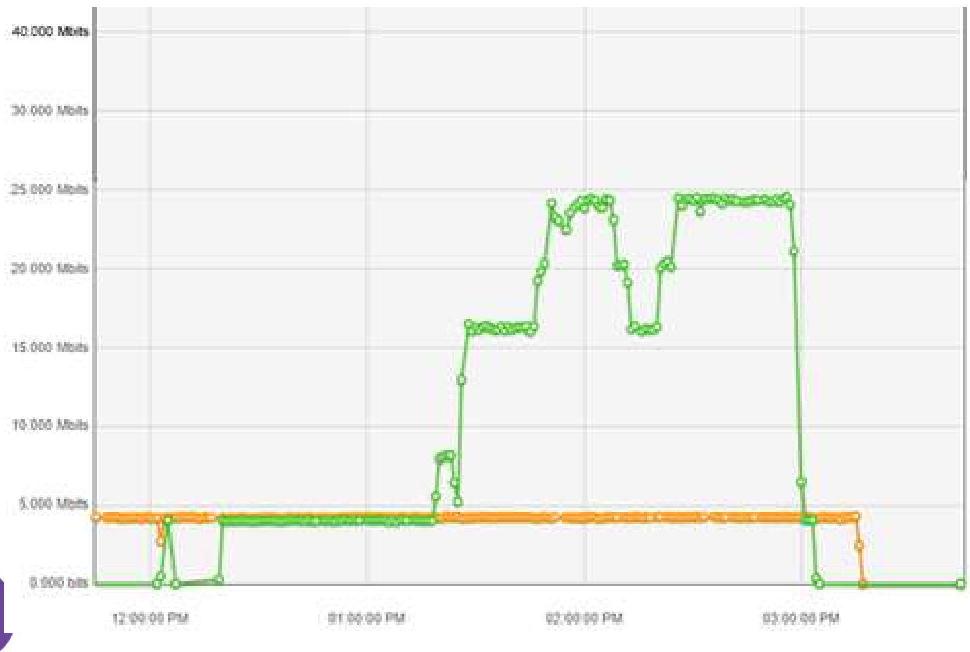

Figure 22 – Phase 1 4G LTE streaming server application recorded metrics

3.1.3 4G LTE Outcomes/Shortfalls

The maximum 'Total Uplink IP Throughput', recorded in Figure 18, was approximately 50% of the lower bound of the target value (Actual ~ 500 kbps, Target = 1,000 to 10, 000 kbps). However, the main device, which was uploading data, i.e., the 360° camera had a wired connection and did not use 4G. As such, it would not be reasonable to expect the target to be reached.

The maximum 'Total Downlink IP Throughput', recorded in Figure 19, was an increase of 650% to the target value for the initial phase (Actual ~ 30,000 kbps, Target = 4, 000 kbps). Two VR headsets and two mobile handsets downloaded the video stream; data suggests that for the initial phase these were sufficient to evidence fulfilment of network downlink requirements.

The 'IP packet latency downlink' in mean milliseconds, recorded in Figure 20, was 96% lower than the target value for the initial phase (Actual ~ 8 ms, Target = 200 ms). This measurement was taken with no other traffic on the 4G radio network.

The 'NTP Mean Jitter' in mean packets, recorded in Figure 21, was in packets and does not match the target value specified in milliseconds for the initial phase. This measurement was taken with no other traffic on the 4G radio network.

The data in Figure 22 shows that after the main portion of the trial (around 2pm and after) extra devices up to a total of six (i.e., two VR headsets and four mobile handsets = 24Mb/s total) were connected to the network. This data combined with the evidence of the poor streaming quality in Figure 17 presents the main shortfall of the 4G LTE network. The end user experience suffered degradation of quality to the point where content was unintelligible when more than four devices were connected.

Based on the bandwidth available this limit was taken as a total of two VR headsets alongside two mobile handsets. However, even with this number of devices, the video and audio quality had to be prioritised, and thus any additional functionality such as two-way communication and on-screen media had to be disabled. Therefore, a 360° video streaming VR training course with 4G connectivity could not be justified as a viable alternative to on-site training.

3.1.4 5G Test Setup

While 5G is already known to provide much higher throughput performance and lower latency compared to 4G LTE, it also provides the required network and data isolation by deploying network slicing as a standard (3GPP Rel.15/16). By doing so, the data arriving at the end-destination of the Independent (Public) networks can be effectively controlled and monitored, along with the network resources and equipment which can also be managed/orchestrated accordingly.

Based on the latency requirements of a use-case, the 5G Core and edge compute capability allow the user data plane (UPF) and application services (VMs, servers, applications, etc.) to run locally at the edge (closer to the end-users), significantly reducing the latency while minimising the backhaul throughput requirements. The high throughput on the downlink (DL) along with the very low latency enable the provision of VR and AR services while also providing a large degree of freedom in terms of video quality and number of connected users.

When analysing network metrics consideration was required for the differing technologies, vendor implementation of statistics and in the case of 5G, the vendor software maturity to support statistics.
An example of a technical difference is the clocking used in 4G which is Network Timing Protocol (NTP) based and 5G which is Precision Timing Protocol (PTP) based.
For the radio technologies, 4G was created using an ip.access solution and 5G created using an Airspan ORAN solution. In 5G statistics there are no measures in place to directly measure PTP, this impacts the capability to monitor, view and report on timing related latency and jitter.

The 5G-ENCODE network architecture between the Private Network (NCC), and the Satellite (NCCI) and Independent (UoB) networks for the VR/AR demonstration is shown in Figure 23 below. From a cellular network perspective, the independent network hosted by the UoB 5GUK test network, represents the public network and acts as an extension of a private network, i.e., NCC network.

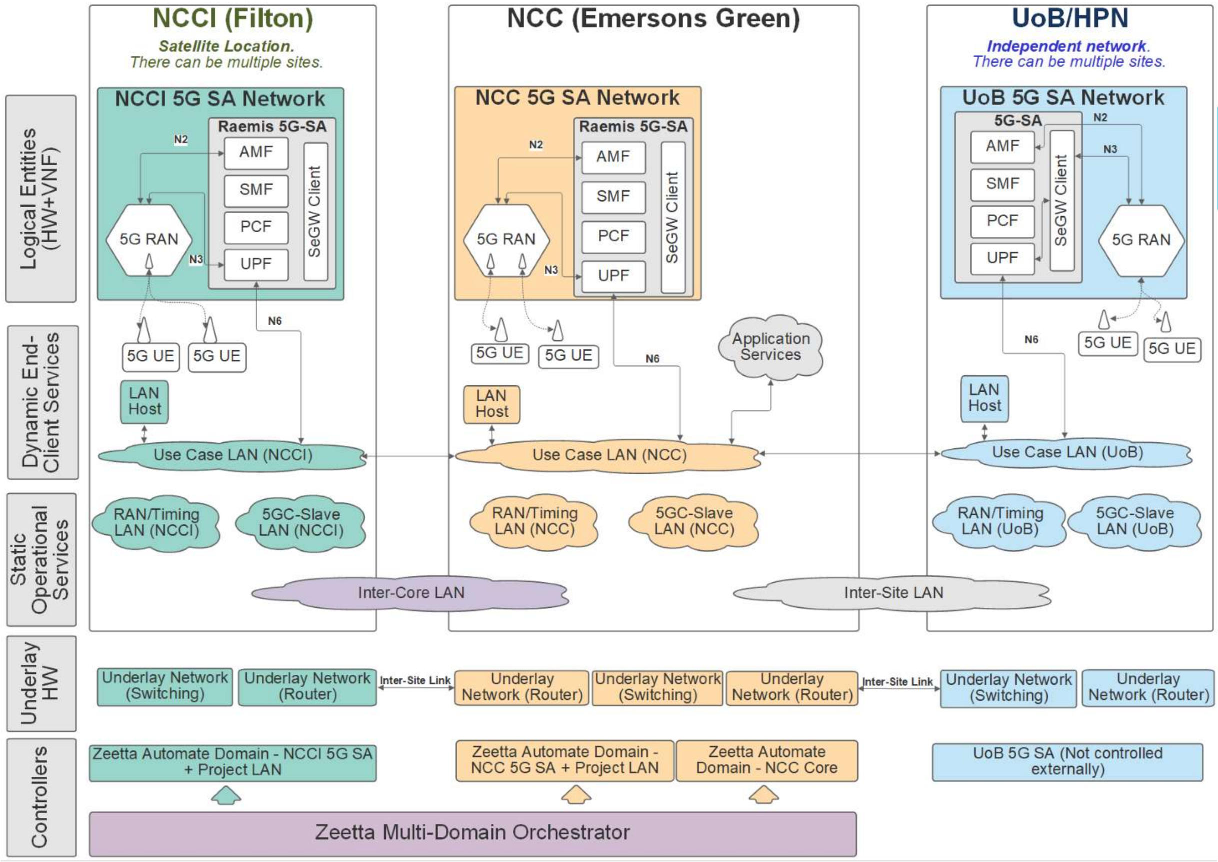

Figure 23 – 5G Encode network architecture

3.1.5 5G Network Metrics

Network performance metrics were collected during the final AR/VR demonstration at Millennium Square and are shown in Table 5 below as KPIs (Key Performance Indexes).

Table 5 – Phase 2 5G measured network metrics

Measured KPIs	Value	Unit
Camera to Server Bandwidth (Total uplink IP throughput)	~3	Mb/s
Server to Users throughput (i.e., Total Cell Throughput) – Total Downlink IP Throughput.	16.1	Mb/s
Server to Users throughput (Individual User Throughput) – App-based DL Throughput on each end-user.	3.22	Mb/s
DL Latency Tolerance – Downlink IP Latency.	3.15	ms
DL Jitter Tolerance – Standard Deviation of the app-based latency.	2.05	ms
% DL Packet Loss Tolerance – Downlink PDCP SDU Air-Interface Percentage Loss Rate.	0.12	%
% DL Packet Drop Rate – Downlink PDCP SDU Percentage Drop Rate.	0.12	%
% UL Packet Drop Rate – Uplink PDCP SDU Percentage Drop Rate.	0	%

These KPIs were derived from a variety of metrics collected from the 5G network (5G Core – open5gs) and the UEs (User Equipment – Android devices/CPEs). The overall network performance was found to be satisfactory. The AR/VR service provisioning showed no problems or interruptions throughout the demonstration.

The total cell DL throughout was 16.1 Mbps on average, reaching a peak of 31Mbps, as shown in Figure 24 below. It should be noted the supported cell capacity was much greater than the one achieved during the demonstration. The wireless link between the 5G NR (New Radio) and the 5G CPE devices was tested before the demonstration, exceeding 700Mbps in DL. Consequently, the stress on the network during the AR/VR demo was well below its throughput limit. It is worth noting that there was a small packet drop in the DL due to some initial inconsistencies between the 5G CPE and the 5G NR. The number of packets dropped was negligible. No dropped packets were detected on the uplink (UL).

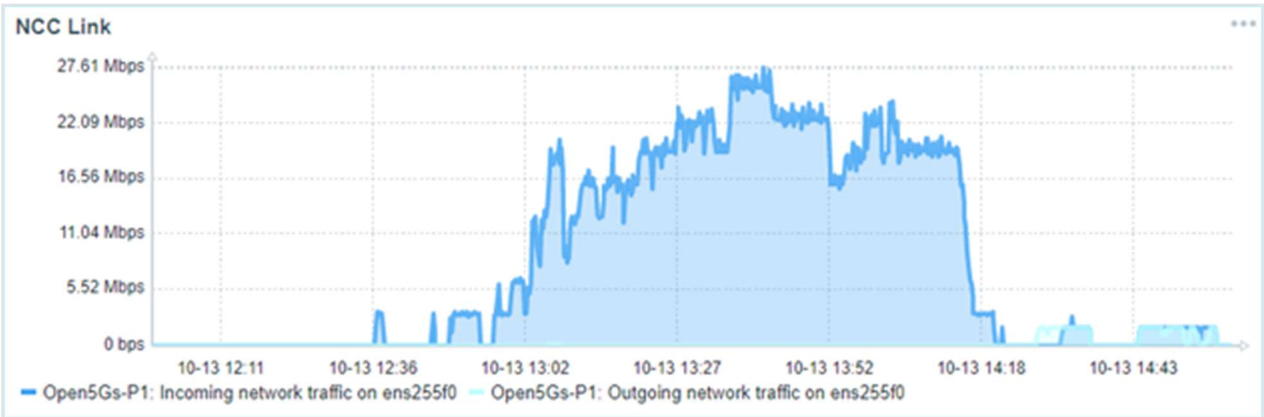

Figure 24 – Phase 2 5G downlink throughput

The average DL latency and jitter between the 5G CPE and the streaming/video server during the AR/VR service provision was measured at 3.22 ms and 2.05 ms, respectively. Hence, the latency performance of the 5GUK Test Network was also satisfactory in terms of end user experience. However, advanced optimization on the 5G network and 5G CPE devices could potentially drop these figures even further.

Metrics were also collected from the streaming server application similar to the Phase 1 trials. Figure 25 below shows the data going into and out of the server – orange representing the upload from the camera and green the downloads to the trainee devices.

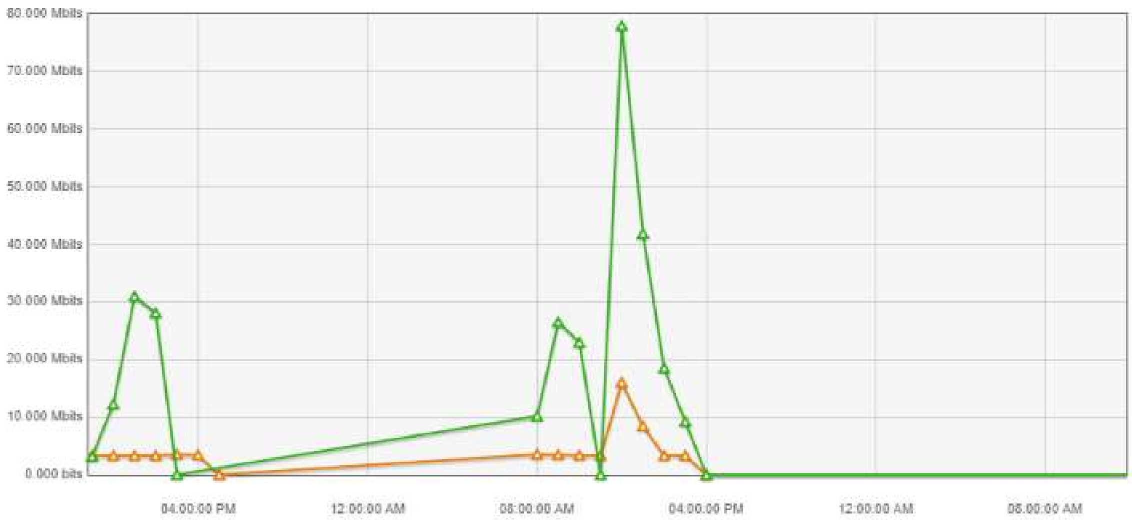

Figure 25 – Phase 2 5G streaming server application recorded metrics

3.1.6 5G Outcomes/Shortfalls

The total uplink IP throughput was not focused on during the network measurements. This was because the 360° camera was again the main uplink contributor and was connected by wire to the internet on the NCC HQ side.

As described above the total downlink IP throughput was on average 16.1Mb/s as the main training devices were the five VR headsets. However, the maximum of 31Mb/s was experienced when up to five additional mobile devices were added. It was promising to see that all of these were able to have consistent and satisfactory video and audio quality. The 5G also enabled the additional functionality such as on-screen media to enhance user experience and improve the knowledge transfer.

To again test the limits of the network, the bitrate of the 360° camera was increased to 15 Mb/s. With five devices downloading this data, as shown in Figure 25, around 75Mb/s was the maximum throughput experienced by the streaming server application during the trial. This effectively brought the streaming server to its limits (i.e., video processing capability) with the VR service characterised by video stuttering and glitching. This highlighted that this part of the system needs further development as the end-to-end link between the server and the 5G CPE could support more than 700 Mbps on the DL.

The 5GUK Test network was stable throughout the demonstration and without any issues. During this demonstration one of the three inhouse developed CPEs presented instability with its network connectivity due to a malfunctioning SIM card. However, the 5GUK team was able to resolve the problem and restore the service for the duration of the demonstration.

3.2 5G Discussion

3.2.1 Benefits of 5G

The benefits recorded by the Phase 2 trials based on the 5G connectivity have been outlined throughout the report but in summary:

1. Data capacity due to available bandwidth (exceeding 700Mbps downlink):
    - Showed significant increase in concurrent devices that can be used with good video and audio quality.
    - Enabled additional functionality such as on-screen media.
    - Highlighted limiting factor in system – i.e., streaming server application, which needs further development for use case.
2. Average speed to each connected device:
    - Ensured good video and audio quality of stream.
3. Low latency (sub 10 milliseconds):
    - Improved trainee experience by decreasing delays between video and audio feeds.
    - Showed potential of two-way communication with minimal delays.

A 5G network within the industrial setting of the NCC HQ also has the potential to facilitate different training courses by increasing mobility of the streaming setup around the factory. A matured and robust system would allow for the 360° video streaming setup to be moved and connected throughout the factory as needed.

3.2.2 Limitations of 5G

A significant limitation in the 5G setup for the particular use case arose from the required hardware. In the current point of time the VR technology has not developed sufficiently to include headsets that allow for direct 5G connections. As a result, the connection had to be over Wi-Fi which can originate from a 5G small cell as described within Section 2.1.2.

However, this introduces additional latency and limits the management of the devices by the core as they are hidden behind a Wi-Fi network; hence limiting the use case architecture which did not allow the benefits from the 5G network to be fully realised in this demonstration.

Also noted most of the 5G-capable devices currently on the market do not support 5G SA operation (disabled on software level), i.e., operating on a pure 5G cellular network without the anchoring 4G cells. 5G Networks and devices are not yet mature enough to support a fast and easy deployment of AR/VR services. Vendors have been slow to implement and support the basic 5G SA functionality, even to their most recent and flagship devices.

To overcome the limited support for 5G SA, the 5GUK engineering team of Smart Internet Lab has developed multiple in-house-built 5G CPE devices. By doing so, 5G SA connectivity could be established and demonstrated between the 5G CPEs and the 5G network, while enabling the provision of 5G services to the AR/VR devices through Wi-Fi 6. These devices are not planned for mass production.

The current inhouse development at Smart Internet Lab is hampered as Wi-Fi services are still pending their integration with the developed CPE devices. The chip-crisis around the world makes it very difficult and expensive to purchase Wi-Fi 6 Access Point (AP) Modules in small numbers (for creation of a Wi-Fi hotspot). Hence, external Wi-Fi 6 APs were connected to the ethernet ports of the CPEs, and traffic was diverted from 5G, to ethernet, then Wi-Fi.

3.3 5G Conclusions

Several conclusions can be drawn regarding the 5G network based on the user feedback and data collected from the Phase 2 trials.

Firstly, the greater bandwidth available and the faster speeds achieved in comparison to 4G LTE significantly improved the use case performance. The video and audio feeds were consistently of a satisfactorily high quality. The number of concurrent devices used was sufficient to justify the VR training course. Most of the users confirmed the immersivity of the experience and were impressed by the quality and knowledge transfer of the course.

However, the trial was unable to fully investigate the capabilities of the 5G network setup by the UoB team. This was because of the highlighted limitation of the streaming server application. Any attempts of significantly increasing the 360° camera bitrate and thus improving quality caused the server to throttle. This resulted in a poor streaming quality observed on the trainee devices. As such the trial was inconclusive in identifying the maximum devices that can be used simultaneously to follow the live stream.

Further, the limitation in the technological advance of the VR headset devices meant that the system could not be fully connected using 5G. This introduces uncertainty in the specific effects of the network. The overall performance is likely to be diminished due to the Wi-Fi connections between the CPEs and the headsets/mobile devices.

Nevertheless, the metrics recorded suggest that the 5G network has the capability to achieve all network targets set out for the project. The downlink exceeding 700Mbps as well as the 3ms and lower latency values were an impressive display for the technology. Based on further testing and optimisation the 5GUK team are optimistic that further improvements can be made to these.

Though as identified in Section 3.2.2, it is important to note that there are difficulties in setting up a 5G SA network. This may impede the introduction of 5G to the wider market of SMEs in the manufacturing sector and beyond until systems are more mature and simpler to install.

The benefits experienced by the use case from the 5G network allowed the project to reach its main objective. The experience was immersive and useful for the users and has the potential of being a viable innovative remote learning solution. Yet, there are still several technological developments that need to be made before this is a matured and robust system. These developments are within the hardware and software on both the use case and the 5G side.

Appendix A – Further Phase 1 User Feedback

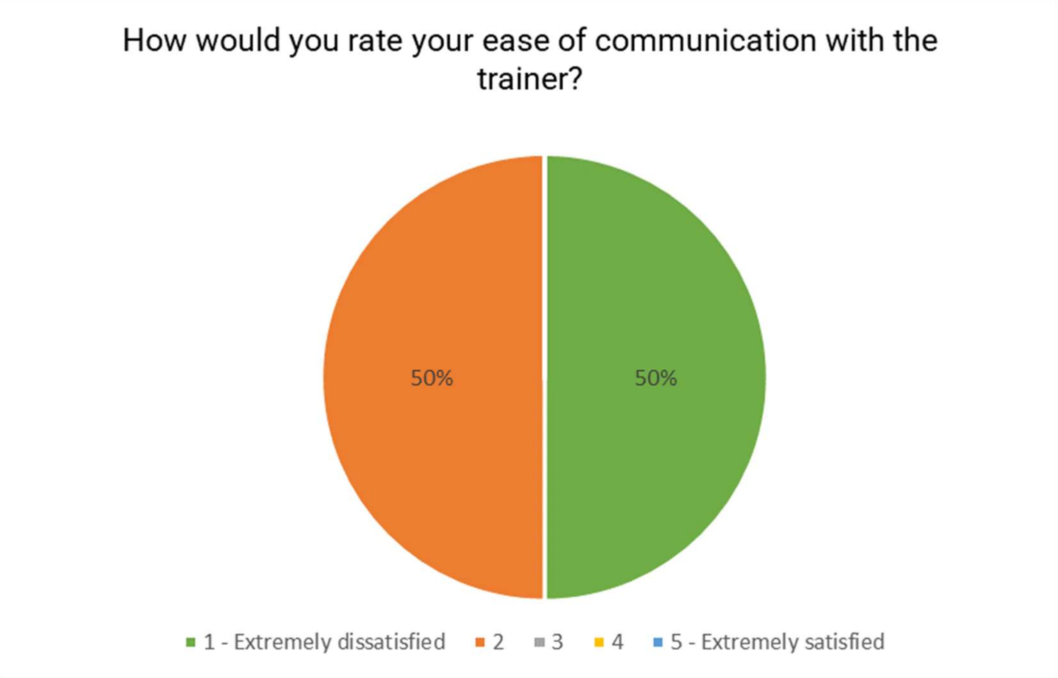

Figure A1 – Phase 1 user feedback regarding ease of communication with trainer

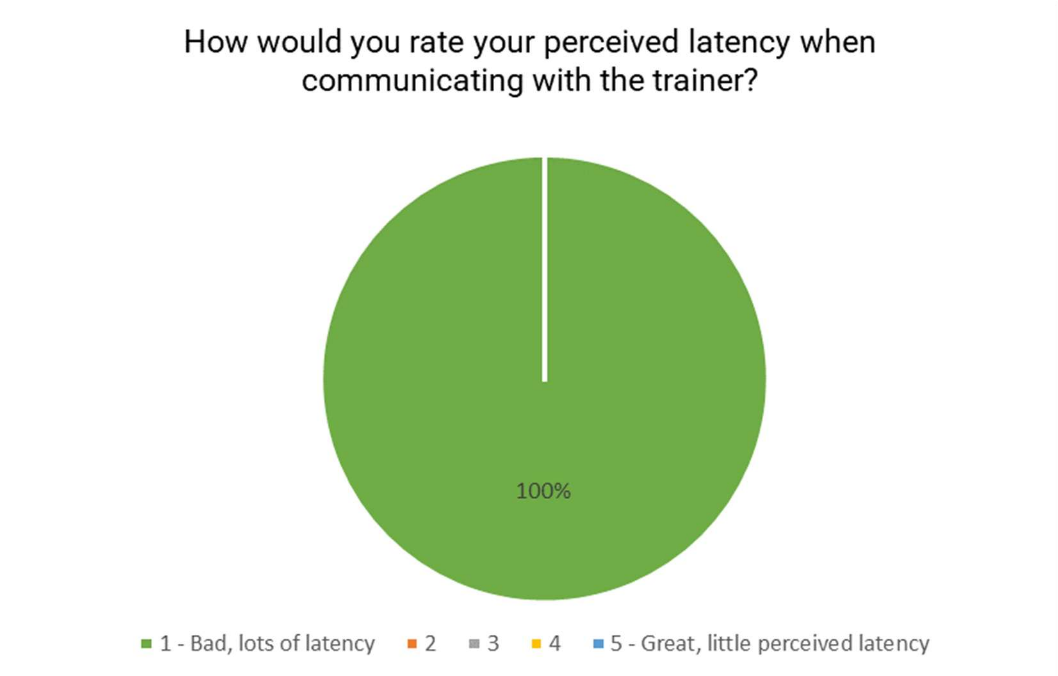

Figure A2 – Phase 1 user feedback regarding perceived latency during communication with trainer

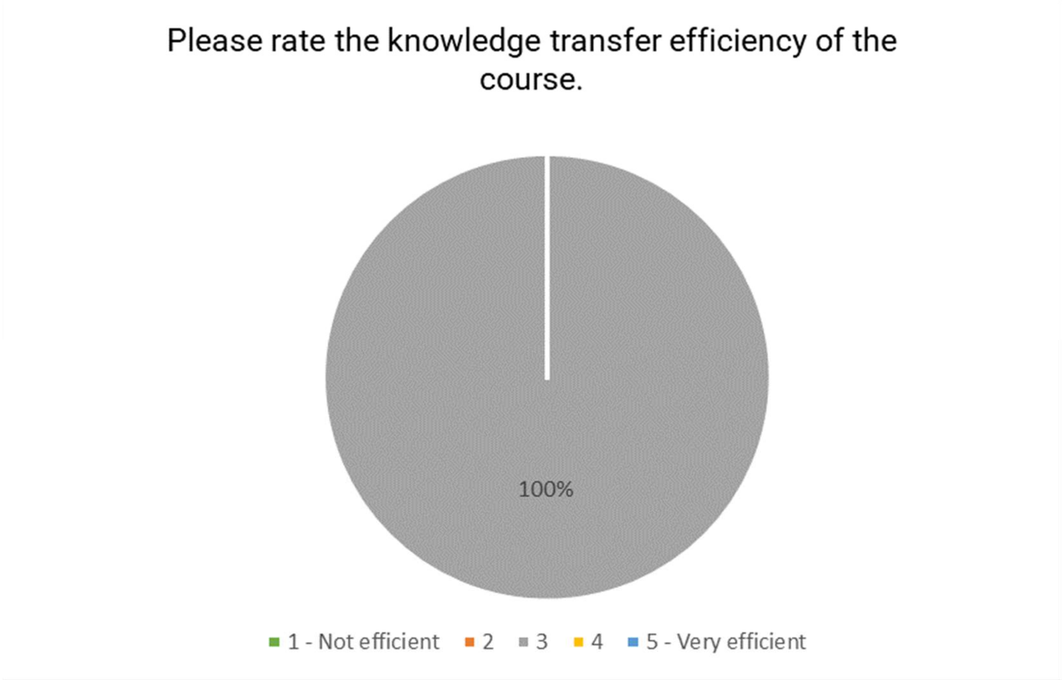

Figure A3 – Phase 1 user feedback regarding knowledge transfer efficiency

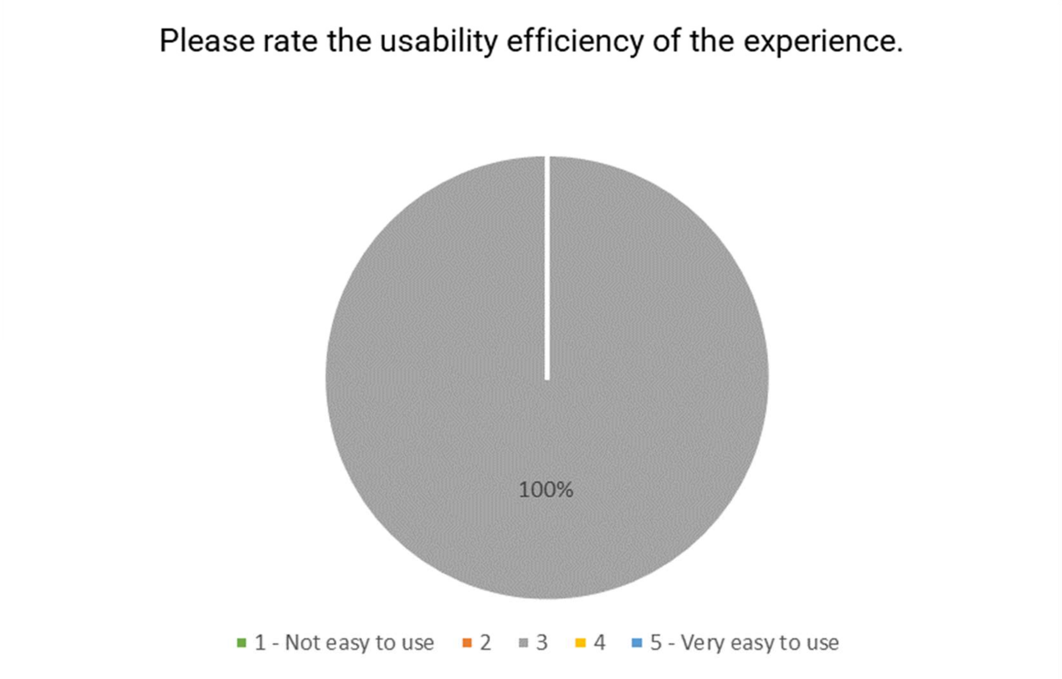

Figure A4 – Phase 1 user feedback regarding usability efficiency

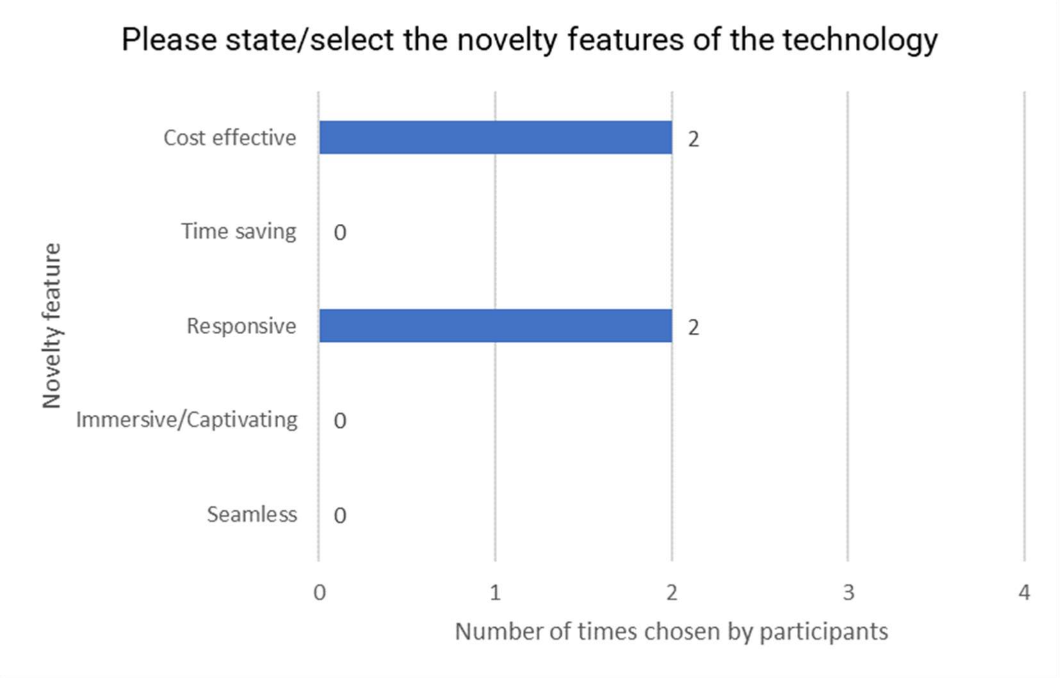

Figure A5 – Phase 1 user feedback regarding novelty features of technology

Appendix B – Further Phase 2 User Feedback

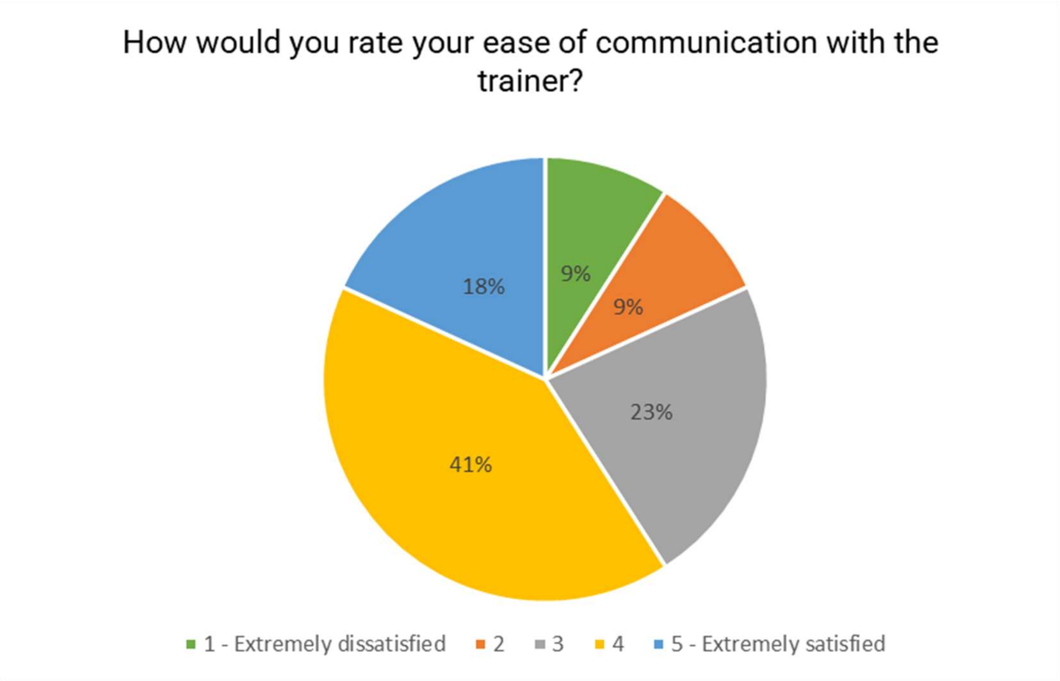

Figure B1 – Phase 2 user feedback regarding ease of communication with trainer

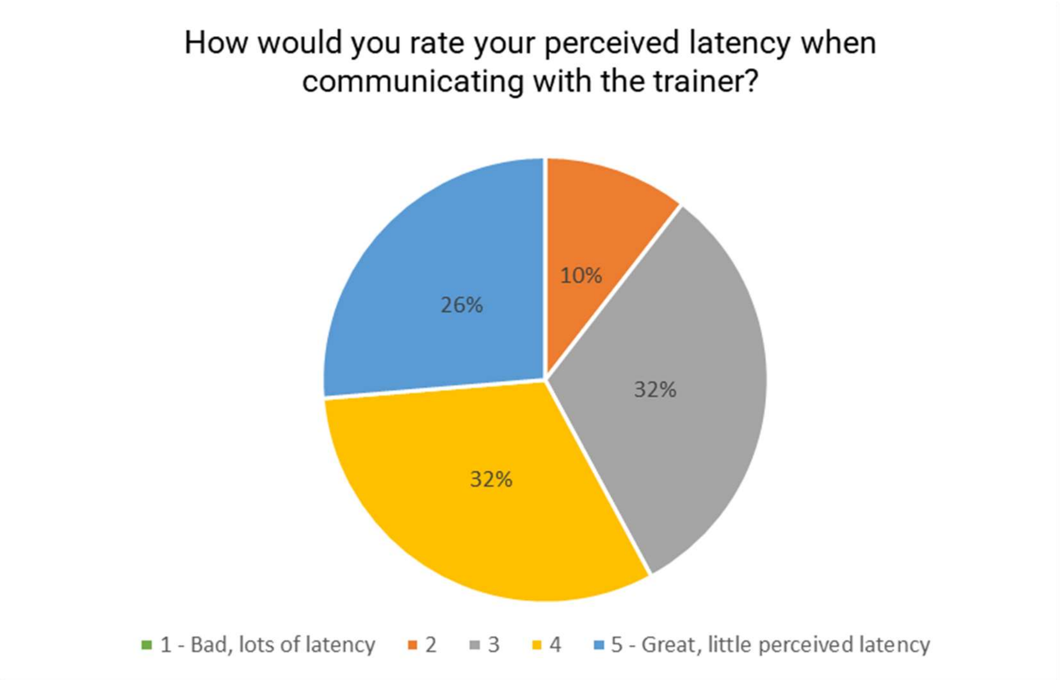

Figure B2 – Phase 2 user feedback regarding perceived latency during communication with trainer

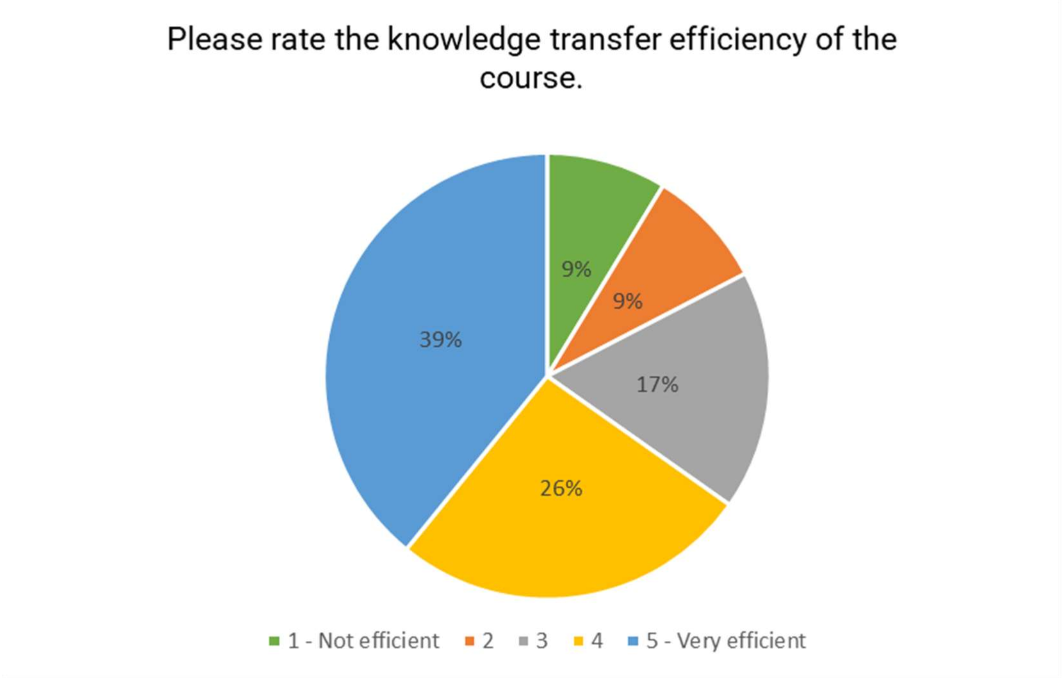

Figure B3 – Phase 2 user feedback regarding knowledge transfer efficiency

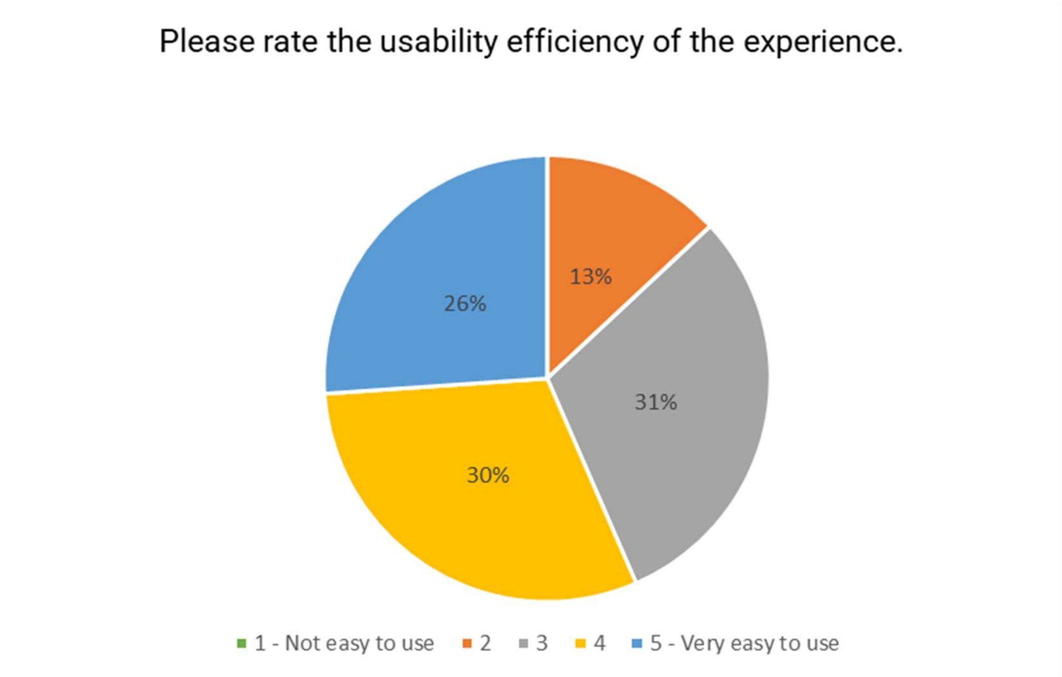

Figure B4 – Phase 2 user feedback regarding usability efficiency

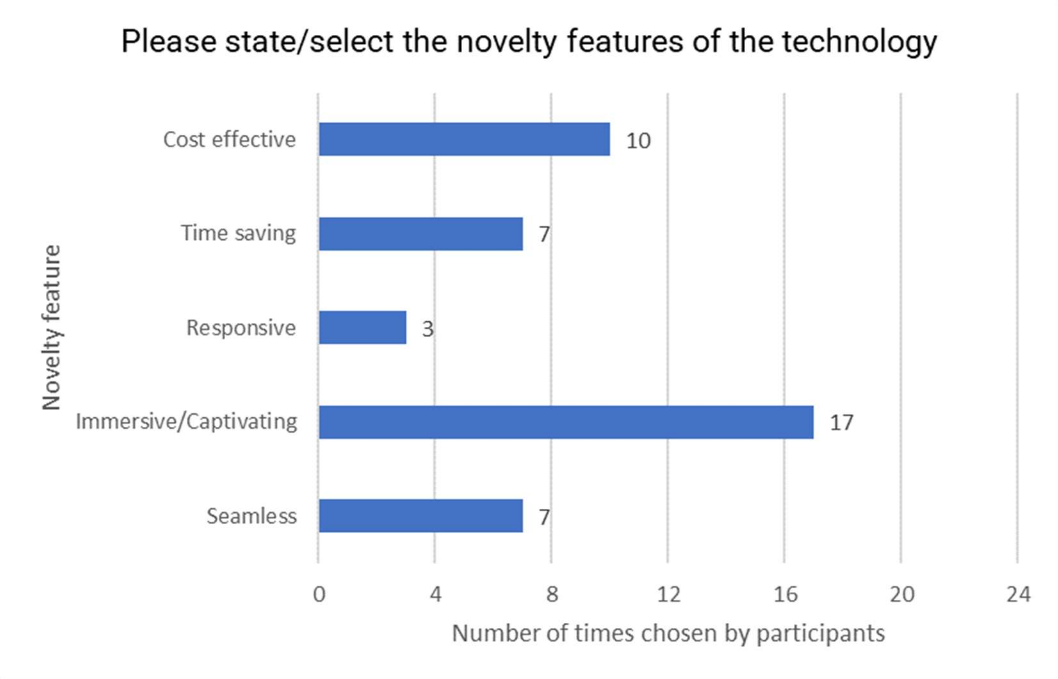

Figure B5 – Phase 2 user feedback regarding novelty features of technology

Appendix C – AR versus VR Use Cases

As part of 5G-Encode, the NCC created and trialled two remote learning solutions – one presented within this report utilising AR technology and one presented in another report utilising 360° video streaming and VR technology. The main motivations for both were relatively similar but the teaching elements that these use cases covered varied. More specifically, the AR solution aimed to completely digitise conventionally on-site practical training courses in a bid to enable effective remote training. While on the other hand, the 360° video streaming VR solution aimed to enhance more traditional webinar style teaching and allow for more immersive remote learning from practical demonstrations in real-time.

As was concluded by both reports on these work packages, the latest demonstrators of the solutions were of satisfactory quality and presented promising digital products. However, it was identified that, for the NCC the AR package has more potential in the long-term based on the significant technological developments that could be made. If it is used as a teaching or training tool, it is possible to create a framework system that could be easily configurable to various topics and courses. This will enable the NCC to offer a wider variety of remote training or create a platform for other providers to utilise as well. On the other hand, the AR packages also has potential of being an effective manufacturing aid. Adding functionality that can validate the composite layup and highlight any possible issues will considerably benefit companies that want to reduce scrap rates.

Nevertheless, the 360° video streaming package in its current format is still a useful capability for the NCC to have and can be implemented in various scenarios for real-time remote teaching. But to improve its immersivity element and fully extract the VR potential, more development must be made in the course setup. For example, having multiple stations around the 360° camera, so the whole field of view is utilised productively. Alternatively, different points of view can be added to allow the users to engage more fully with the practical demonstration presented.