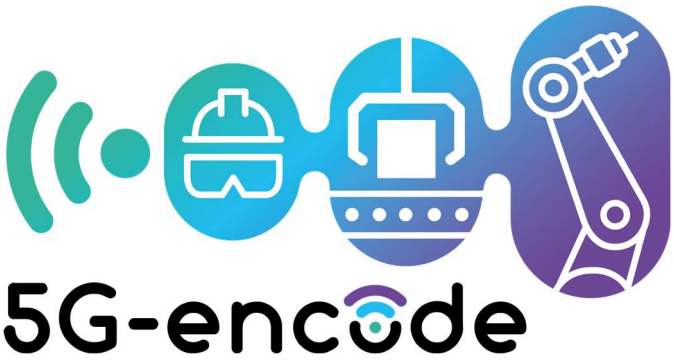

Programme Closure Report

Produced by Zeetta **Mar 2022**

DOCUMENT VERSION CONTROL

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Version Control

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EXECUTIVE SUMMARY

The 5G ENCODE project was defined to prove the value of 5G to industrial and manufacturing processes. To understand and realise the value of 5G in this context the following objectives needed inclusion:

- Enhanced Mobile Broadband (eMBB)
- Massive Machine Type Communication (mMTC)
- Ultra-Reliable Low-Latency Communication (URLLC)

Demonstrating the above objective in an industrial context required differing use cases, namely:

1. Virtual Reality (VR) & Augmented Reality (AR)
2. Asset Tracking
3. Liquid Resin Infusion (LRI) and Automated Preforming Cell (APC) technologies

The program required multiple partners working in a collaborative manner to deliver the use cases whilst also exploring use cases for:

- Neutral Hosting (NH)
- Network probing and monitoring
- Network visualisation and service management

The program included a feasibility study for:

- Remote Haptics

The project reports are grouped by use case and collaboration partners with Zeetta Networks as program lead assembling this program summary report.

Overall, the 5G Encode programme was a success and met its time, cost, and quality objectives.

CONTENTS

FIGURES AND TABLES

ABBREVIATIONS

4G LTE	Fourth Generation Long-Term Evolution
5G	Fifth Generation
5GTT	5G Testbeds and Trials
APC	Automated Preforming Cell
AR	Augmented Reality
BMS	Bristol Millennium Square
BR	Benefits Realisation
CR	Change Request
DCMS	Department for Digital, Culture, Media and Sport
DETI	Department of Enterprise Trade, and Investment
eMBB	Enhanced Mobile Broadband
ERP	Enterprise Resource Planning
JOTS	Joint Operator Technical Specification
LRI	Liquid Resin Infusion
LTE	Long Term Evolution
MDO	Multiple Domain Orchestration
mMTC	Massive Mobile Machine Type
MS	Milestone
MTU	Maximum Transport Unit
NCC	National Composites Centre
NH	Neutral Hosting
OEE	Overall Equipment Efficiency
ORAN	Open RAN
PCN	Private Cellular Network
RAN	Radio Access Network

SME	Small and Medium Enterprises
TPO	Total Production Optimization
TUK	Telefonica UK
UoB	University of Bristol
URLLC	Ultra-Reliable Low Latency Communications
VR	Virtual Reality
WECA	West of England Combined Authority

PROGRAMME SUMMARY

Purpose

The 5G-ENCODE Project is a £9 million collaborative project aiming to develop clear business cases and value propositions for 5G applications in 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 (5GTT). The project is one of the UK Government's biggest investments in 5G for manufacturing to date and is led by Zeetta Networks Ltd. Other consortia partners include the National Composites Centre (NCC), Telefonica, Siemens, Toshiba, Solvay, Plataine, Mativision, and the University of Bristol while the West of England Combined Authority (WECA) provides additional support through their Department of Enterprise Trade, and Investment (DETI) Programme.

Objectives

The 5G-ENCODE project will deliver a private 5G testbed within the National Composites Centre (NCC) and demonstrate new business models (neutral hosting) and technologies (network slicing and splicing) and their value proposition to three key digital engineering capabilities for composite manufacturing:

1. Application of AR/VR to support design, training, and advanced Human– Machine interfacing to enhance quality of manual layup of composites
2. Condition monitoring and tracking of time sensitive assets i.e. composite materials to enhance shop floor operational efficiency and compliance
3. Wireless real time in process monitoring inside harsh process environment such as ovens as a steppingstone to full machine autonomy

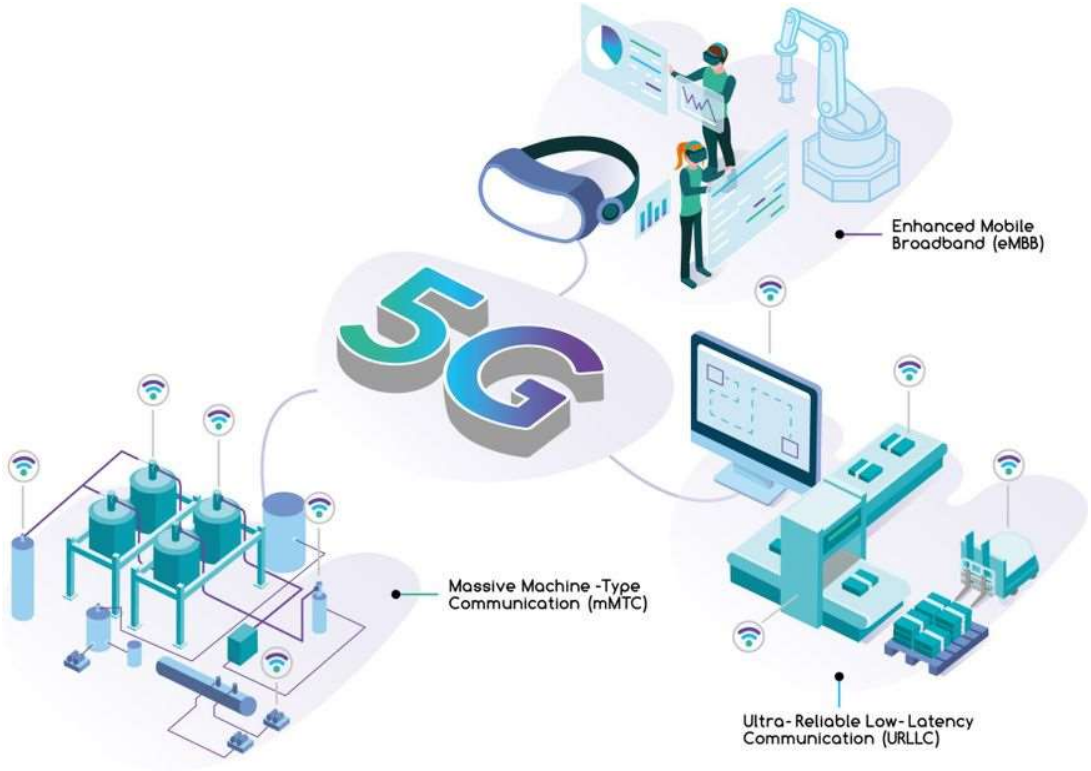

Figure 1: 5G Encode Overview

Partners and Collaborators

The reports below can all be found on the 5G Encode website https://www.5g-encode.com/media-and-publications.

The collaborating partners worked together as follows:

Work Package	Work Package	Sub-work / Use Case	Use Case Lead	Collaborators
WP1	Program Management		Zeetta Networks	
WP2	Network Design and implementation	LTE network 5G network	NCC	Toshiba, Telefonica & University of Bristol
WP3	Industrial use case	Augmented Reality (AR)	NCC	Mativision
WP3	Industrial use case	Virtual Reality (VR)	NCC	Mativision
WP3	Industrial use case	Asset Tracking	NCC	Plataine
WP3	Industrial use case	Automated Preforming Control - APC	NCC	
WP3	Industrial use case	Multi-sensory, in-process monitoring and analytics - LRI	NCC	Toshiba
WP3	Cross use case	Neutral hosting	Telefonica	
WP3	Cross use case	Out of factory asset management	Solvay	
WP3	Cross use case	Network monitoring using probes	Accedian	
WP3	Cross use case	Single and Multi-Domain Service	Zeetta Network	

		Management (slicing)		
WP3	All Use cases	Benefits Realisation	Zeetta Network	
WP3	Feasibility Study	Remote Haptics Feasibility Study	NCC	

Figure 2: Activity Reports

Collaborator specific additional notes:

Zeetta Networks – as well as collaborating on the service management aspects of the network configuration and visualization, Zeetta Networks are the project lead

Accedian - joined the Encode program during execution. The objective for Accedian was to provide a performance monitoring capability and show that their Skylight solution enables manufacturers to ensure that the performance benefits promised by 5G meet expectation and lead to the successful delivery of the use cases demonstrating the business case for investment in private 5G.

Scope

The main deliverable of the project is an easily accessible 5G testbed which the UK manufacturing businesses can use for experimentation and new product and services development with minimal risk to their own production facilities. Other key outcomes include:

- Proof of the business viability of 5G private networks targeting the UK manufacturing industry
- Stress-test a carefully selected number of key 5G use cases / proof of concepts (infrastructure, network architecture and information exchanges) across a targeted supply chains to eliminate the risk of implementation for upcoming large-scale UK based future manufacturing programmes
- Combining private and public 5G environments and the seamless transition of goods and services across domains
- Build on existing 5G investment and established testbed by using 5GUK Test Network in Bristol Millennium Square (BMS)

- Exploring the interaction between advanced business models (neutral hosting) and 5G technologies (network splicing and slicing) for better service delivery in a demanding environment

The project meets DCMS requirements as follows:

- Led by private sector, including SMEs: Zeetta Networks is a private SME with specialising in 5G networking technology (network slicing and splicing). Other industry players include Telefonica, Siemens, etc.
- Use of local infrastructure assets: The project makes use of the 5GUK Test Network in Bristol Millennium Square (BMS)
- Explore 5G deployment and industrial use cases in the manufacturing: The project addresses three key industrial use cases
- Seeking involvement from a range of companies: The consortium includes Tier 1 operator, large industrial players, disruptive technology Small and Medium Enterprises (SME), leading 5G research institute and representatives from the high value manufacturing industry

Achievements / Overall Result

The following sections are taken from the full detailed reports stored the section: 5G Encode - Media publications (5g-encode.com) Case Study Final Reports – Phase 2 introduction of 5G

Use Case - Virtual Reality

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 internetbased 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.

This use case 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 Long Term Evolution (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.

Augmented Reality

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.

This use case evaluates the use of latest AR software, hardware, and 5G connectivity to demonstrate a fully immersive AR remote training solution. This solution is used to guide the user through the manual composite manufacturing process of one of the practical courses offered by the NCC. On-screen text instructions, overlayed 3D graphics, and tutorial videos support the trainees wearing the AR headgear. The work package also relies on 5G's reliable, safe, high bandwidth and low latency connectivity to facilitate high quality two-way communication (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 four trainees across two sessions. None of the participants indicated that the solution was of sufficient quality to justify its use over conventional on-site training. The root cause for this was not found to be the network connectivity, but the initial development of the AR application.

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, almost 79% of users were satisfied with use of the package over on-site courses. The network provided sufficient connectivity to enable the two-way communication function with good quality which was appreciated by all users. Metrics exceeding 700 megabits per second download speed and around 3 milliseconds latency were recorded.

The immersive technologies tested in this report are shown to be a good option for remote training but require high quality digitisation and integration in the process. The 5G technology was shown to be reliable and high-performance with no significant or lasting interruptions throughout the two days of demonstration sessions at Millennium Square. However, the use case was not very heavily reliant on the network because the only

feature relying on it i.e., two-way communication, was only used intermittently for relatively short periods of time.

Future developments can include features that increase the use of 5G with the development of online libraries containing interactive digital content. This development should also modularise the solution and improve its adaptability and cross application re-use.

The AR technology must reach a more mature and robust stage before being applied in real world cases. To enable this wider-scale adoption access to operational public or private 5G networks is a prerequisite.

Asset Tracking

In-factory

An autonomous asset tracking solution, as the one proposed by this use case, offers the opportunity to effectively track mobile tools and assets such that current unproductive time spent searching for these items is minimised. When applied to time sensitive materials, such as prepreg carbon composites, this solution could also reliably monitor product outlife and a tooling maintenance schedule to minimise material wastage and ensure representative product traceability information, as well as high quality manufacturing standards of components.

This use case evaluates key features, typical of an automated fibre placement process – a high value manufacturing method to produce composite parts, as well as post processing operations (e.g. curing, non-destructive testing, metrology scanning).

The proposed asset tracking solution relies on both software and hardware components, with the existing sensor gates deployed on the NCC factory floor communicating real time data to a live web application via a 4G, 5G or wired power over ethernet (POE) connection.

Based on the 4G asset tracking baseline findings, it was concluded that the performance of the test bed was directly linked to the network stability. 5G technology showed the potential to enhance the asset tracking solution by enabling connectivity to a much wider range of devices and assets simultaneously, without compromising its stability, offering improved speeds and latency.

This digital asset tracking solution showed great benefits in the form of productivity improvement, cost savings and better tooling control. By ensuring easy access to real time asset location information, it is possible to more efficiently plan a manufacturing schedule based on asset availability, minimising the unproductive time spent on searching and locating tooling or materials as production commences. It has been assessed that a 93% reduction in search time per job is possible with the present asset tracking solution, removing the likelihood of rescheduling a production run due to item unavailability.

Another major benefit of the proposed asset tracking solution is the ability to closely monitor stock life and availability, leading to an improved stock management and minimal material wastage, with implicit cost savings of at least £56,000 per year for production facilities similar in size and manufacturing rates to the NCC. Also, by closely monitoring the usage of tooling in production cycles, it is possible to reliably record and schedule maintenance, and, thus, ensure a high-quality standard of production.

The asset tracking technology detailed in the present report showed to be an effective means to wirelessly monitor both item location and material out-life in a production environment, but for a relatively small number of products. It is of interest for this use case to explore further the 5G capabilities for asset tracking and assess how a higher number of assets managed by the system would impact the performance and accuracy of the test bed. Seeking an out-of-factory tracking solution is also a scope of work the NCC would like to trial in the near future; however, access to public or private 5G networks outside production facilities is a prerequisite.

Out-of-factory

The asset tracking evaluation work package was delivered in collaboration with Plataine Ltd which provided the Total Production Optimization (TPO) application and the NCC, Bristol which provided the test bed for the private 5G technology evaluation. The NCC test bed was delivered together with Zeetta Networks, Toshiba, Mativision, Plataine, Siemens, Telefonica, Accedian and the High-Performance Networks Group from the University of Bristol as partners.

As a leading supplier of composite materials, Solvay evaluated the potential of the automated asset tracking technology from a material manufacturer perspective. Solvay,

based at a site in Wrexham, supplied to the NCC the composite materials required for the evaluation of the automated asset tracking use case from a material manufacturer site to a customer site perspective.

Figure 3: Out-of-Factory Process Flow

The project highlighted the potential benefits of automated asset tracking in terms of waste reduction and Overall Equipment Efficiency (OEE) improvement from a composite materials manufacturer perspective. Potential for full automation of currently manual or semi-automatic quality tasks or Enterprise Resource Planning (ERP) transactions was also highlighted. Solvay has decided to pursue further the evaluation of automated asset tracking technologies following this project.

At this stage the benefits of, in factory, 5G cellular technology to support an automated asset tracking system deployment at the Solvay, Wrexham site compared to a conventional PoE+ approach remains unclear. Further evaluation would be required before any full deployment of automated asset tracking across the Solvay's multiple Wrexham sites.

Automated Preforming Control (APC)

This use case assesses multi-sensory, in-process monitoring and analytics in an industrial use case relating to in-process verification of composite materials using a vision-based system. The main barrier to these types of verification systems being more widely accepted across industry is the significant infrastructure requirements for them to operate effectively. These requirements are driven from the need to process the massive amounts of data generated and the need for low latency feedback, which leads to them needing to be installed in fixed locations with large set up, and integration costs.

This use case aims to demonstrate how a decrease in infrastructure requirements and increased in flexibility offered by exploiting 5G capabilities, can make this technology more accessible for industry.

5G has ultra-fast, high bandwidth, low latency capability enabling large amounts of data to be sent and received wirelessly in near real time. The Gigabit uplink and downlink speeds present an opportunity for this use case as vast amounts of data are generated during each scan. The high throughput ability of 5G combined with the ultra-low latency theoretically lend themselves perfectly to this application as large volumes of data can be communicated in near real time.

To assess feasibility and understand solution architecture prior to 5G network availability, a baseline test was conducted using 4G LTE on a similar vision system. This test proved that vision systems of this nature can communicate data using cellular technology, however low 4G communication speeds led to the scan time being significantly increased while the quality of the gathered data was reduced.

Upgrading the industrial vision system at the NCC to 5G was successful and allowed data to be communicated to a virtual server in near real time, achieving latency values in the region of 14ms. The uplink throughput was still not sufficient to run a scan at the same parameters as the original wired set up but vastly improved compared to 4G. A maximum uplink throughput achieved using 5G was 18Mbps (2.25MBps), far from the 900Mbps seen when using CAT7 cable. The lack of comparative communication speed led to data fragmentation and network instabilities when attempting to pass large volumes of data across the network, often leading to a cease in data flow. The root cause of this has not been fully identified, however, a reduction in uplink data volume, through reduction of Maximum Transport Unit (MTU) size and scan speed, vastly improved the stability of the connection and the quality of the output.

The 5G connection did allow the processing PC to be removed from the system, significantly reducing the weight and footprint of the end effector from 45kg to 3.5kg. This allowed the use of a smaller collaborative robot to accurately position the system reducing robot system cost (~88% reduction) and, in turn vastly reducing the integration cost required to set up when compared to the original deployment (~98% reduction).

The use of industrial 5G for an application such as this is possible but there are trade-offs that must be considered. There is a significant reduction in both robot system cost and integration cost, leading to a much more flexible and easily deployable system. However,

until an increase in 5G uplink throughput is possible, the time to scan will be greatly increased to achieve the same quality of output.

Liquid Resin Infusion (LRI)

This use cases assesses multi-sensory, in-process monitoring and analytics in closed loop Liquid Resin Infusion (LRI). LRI is a process used by the aerospace, automotive, marine and several other industries to create composite components. It has many benefits over prepreg, such as cheaper material costs and faster manufacturing times – however is highly dependent on the skill of the operator, is very manual, and often produces many scrap components when developing new parts. There is a need to automate LRI to make parts right-every-time, reduce the environmental impact by generating less scrap, and lower cost and manufacturing time.

The closed loop LRI system utilised 5G and digital technologies to improve the process. The system used a sensor array to monitor key LRI process variables and sent this data to a control model. The model decided how the process should be altered in real time and sent commands to a feedback system that implemented the decisions. A visualisation system used dashboards to display process data in real-time and generated a traceability report for each part. All sensor data and control commands were sent over 5G.

To enable a modern closed loop system to work effectively there are numerous requirements to consider. A high speed, low latency, highly reliable network is needed to transfer process data across. Next, because the amount of data needed to properly model a manufacturing process could be vast, the network needs to be able to handle large numbers of sensors connecting to it. In practice the sensors need to connect to the system wirelessly as attempting to connect a huge number of wired sensors is impractical. Finally, a high-performance computing capability – located on the edge – is needed to run complex models (for instance AI) that will control the manufacturing process. 5G has the potential to meet these requirements through characteristics including Ultra-Reliable Low Latency Communication (URLLC), edge computing, and massive Machine Type Communication (mMTC - allowing thousands of devices to connect to the network at once).

The system was initially tested on a 4G network to establish a baseline, and then tested on a bespoke 5G network to assess if there was a discernible increase in real world

performance of the use case. Additionally, the system was tested on a low cost off-the-shelf/open source 5G network; its performance was assessed to understand if this cheaper system could allow smaller companies to leverage the benefits of 5G.

The closed loop LRI system realised numerous benefits. It led to reduced manufacturing labour costs of around 25% while the live dashboards gave engineers a clear view of the process and allowed them to reduce cure cycle time by around 50%. Using wireless 5G communication enabled the system to be flexibly deployed anywhere in the factory. Finally, the automatic generation of the part traceability report saved over 8 hour of engineering time and associated costs.

Overall, the use case was able to operate well over 5G, however network dropouts due to poor reliability caused some data loss – more work is required to enhance device stability on the 5G Standalone Open RAN network (5G SA ORAN).

Reliability issues were also seen with the off-the-shelf/open source 5G network.

There was not a discernible performance increase seen over the 4G baseline. The use case however was a small-scale demonstrator – it is likely that if the system was expanded to a more representative scale (such as an aircraft wing manufacturing process) the advantages of 5G would become visible.

Network monitoring using probes

Accedian, the probe supplier, has been a long-standing provider of network and application performance monitoring to both Service Provider and Enterprise markets and they had recognised the new opportunities that 5G would offer to Industry. Research by the CapGemini Research Institute concluded that "2 out of 3 industrial companies believe that guaranteed quality of service is critical for their digital transformation" and with 5G holding the key to unlocking digital transformation for manufacturers, both in the UK and around the world, monitoring the performance of both the 5G network and the applications driving the 5G use cases of mMTC, eMBB and URLLC, is a critical success factor.

Project Encode provided Accedian with an ideal opportunity to validate the value of its performance monitoring and test generation virtual platform, Skylight Analytics, to in the

manufacturing industry by supporting their digital transformation journey and helping companies to realise the performance and reliability benefits of 5G.

Within Project Encode, Skylight was deployed at the National Composites Centre (NCC) and delivered granular and accurate real-time visibility, anomaly detection, and analytics on the performance of 5G-ENCODE's private 5G network and the applications that run over it. Skylight was able to support the project's goal to accelerate the realisation of the benefits of 5G for their key business use cases; in-factory and in-transit asset tracking, virtual 360-degree video training and closed loop manufacturing in Liquid Resin Infusion. The key results being:

1. The simplification of fault identification and resolution to enable non technically skilled staff to identify use case impacting issues and what the issue was and what the possible root cause was.
2. The presentation of highly accurate and granular performance data to enable technical staff to trouble-shoot use case impacting issues to reduce downtime
3. The ability to proactively identify performance degradations that would lead to negative impact on the use cases.

Single and Mult-Domain Service Management (slicing)

5G connectivity services are being explored not only by the incumbent global mobile network operators but also by enterprises looking to have more secure and flexible mobile connectivity solutions for their various connectivity requirements. In an already complex enterprise IT environment, 5G will yet add another level of complexity for those having to manage their networks.

Abstracting away the underlying complexity of provisioning and managing a multi-site and multi-technology enterprise network environment provides great value for enterprises. As Network engineering teams managing these enterprise networks might not have access to the expertise typically required to fully manage this ever-growing complexity, solutions to simplify daily operations are of critical importance.

Zeetta NetOS® and Zeetta Multiple Domain Orchestration (MDO) provide this level of abstraction for the case of single site and multi-site enterprise networks respectively. These tools provide network administrators with a single dashboard for management of various

network services - including 5G PCN services - allowing end to end services to be deployed seamlessly across various network infrastructure devices and application servers.

At 5G-ENCODE, Zeetta deployed a cloud based Multi-Domain Orchestrator (MDO) and demonstrated the benefits of using this application by creating a multi-domain end-to-end connectivity slice that was automatically provisioned across different network domains, reducing the time required to enable service connectivity and avoiding manual intervention in the various network devices.

Neutral Hosting

The requirements placed in Telefonica UK (TUK) from the Consortium Agreement included allocation of test spectrum for in-building use if needed, consultancy and SIM cards to support possible public network utilization. The project also asked TUK to investigate the provision of neutral hosting integration, whilst outside the agreed scope of the project TUK agreed to investigate what was possible.

Whilst not included in the original Consortium Agreement, TUK were asked if they could support neutral hosting solution. TUK whilst not contracted to deliver a solution investigated what was possible in the timescales. Following that investigation TUK found that they were unable to support outdoor Use Case 2 (AR/VR) for 5G Encode Phase 2. The project had to find another solution and selected a lower cost core and Radio Access Network (RAN) solution that was available to support the project. TUK had also investigated a Nokia based standalone solution where the RAN and core were supported by TUK, but again the costs were significant and were deemed to be too high.

TUK's analysis clearly showed that connecting private networks to their public network was not possible within the planned project budget and timescale, due to complexity of the integration task, license obligations and security concerns. TUK reviewed three solutions that the project could adopt. The Joint Operators Technical Specification (JOTS) seemed the most realistic, but this was still complex to integrate when the private network supplied by the public mobile operator and with a cost that was beyond the budget of the project. In the end it was simply not possible to deliver a JOTS solution to the timescale of the project, consequently, the integration idea was abandoned.

It should be noted that TUK were only a minor partner in this project from the beginning and never intended to deliver the network solution. And this was reflected in our modest claim for this project.

In the 5G Discussion section of this document the technical and logistical lessons learned are discussed along with recommendations for future projects to consider.

Remote Haptics Feasibility Study

In this work, haptic robot control protocols have been integrated into a teleoperation solution where an industrial robot located at the Bristol Robotics Laboratory is operated from the National Composites Centre.

The teleoperation is cabled to function in this feasibility study with no 5G cellular used in the study. This study was to create a benchmark for use in future projects.

The need for robot teleoperation within the industry remains for use-cases of which the environment is too hazardous for direct human operation and too complex for automation. For further steps to be made in robot teleoperation there need to be intuitive systems designed that allows an operator to control the robot with confidence. A system is proposed that uses hand tracking, haptic feedback, and an immersive experience to actuate a robotic arm from a distance for which optical fibre and network cables are used to facilitate the network needs.

The robotic actuation using the combination of a haptic hand tracking device and a haptic protocol that allows the operator to move the robot by moving his/her hand. The immersive experience using a stereo camera to capture the robot's environment and a Virtual Reality (VR)-headset to make this content visible for the operator. The teleoperation is cabled to function as a benchmark in this feasibility study. The network consists of a combination of optical fibre, CAT 6 Ethernet and universal serial bus cables. The main connections within the network are limited to a 1 Gbps maximum throughput.

During testing of the solution it was measured that the maximum data throughput was 27 Mbps. The current 5G networking capability allows for an uplink of 57 Mbps and a downlink of 410 Mbps. With this it can be concluded that 5G could be integrated within the current solution. To limit the potential project risk an initial study was undertaken where

the operation of a robot arm was completely virtual proving that haptic control of an industrial robot arm is indeed feasible. This time around project risk was again mitigated by first testing the network and the solution using a cable. By doing this it was possible to prove the feasibility of 5G in a short time frame.

Detailed Reports

Full reports are stored the section: 5G Encode - Media publications (5g-encode.com) Case Study Final Reports – Phase 2 introduction of 5G

MILESTONES & DELIVERABLES

All planned and new milestones were completed as planned or through change requests identified in the change section.

Below is a summary of the Milestones with the detail contained in the fortnightly report to DCMS.

#	Milestone	Delivery status
MS1	MS1: Design for the phase one (i.e. 4G and/or Wi-Fi) network architecture and functional specification is agreed	Completed
MS2.1	MS2.1: Draft benefits realisation metrics recorded	Completed
MS2.2	MS2.2: Benefits Realisation framework	Completed
MS3	MS3.1: ITT is issued for the equipment and services needed in the phase one 4G and/or Wi-Fi network	Completed
	MS3.2: Product descriptions for Use Cases evaluated against network architecture	Completed
MS4	MS4: Final Collaboration Plan	Completed
MS5	MS5: Phase one 4G and/or Wi-Fi network has been deployed	Completed
MS6	MS6: A Case Study about the phase one 4G and/or Wi-Fi network is available to download from the project website	Completed
MS7	MS7: ITT is issued for the equipment and services needed in the phase two 5G network	Completed
MS7.1	MS 7.1 Interim Reports	Completed
MS8	MS8: Phase two (i.e. 5G) network has been deployed	Completed
MS9	MS9: A showcase event is held to share learning from the two innovation use cases that the 5G network has enabled	Completed
MS10	MS10: A final project report is provided to DCMS	Completed
MS11	MS11: A project closure and review meeting is held with the project board and DCMS	Completed
M12	MS13: Collaboration Topic: Project Closure	Completed

Figure 4: Delivery Milestones

SCHEDULE

Planned

The programme was split into three distinct work packages as follows

Work package 1: Programme Management

Led by Zeetta Networks and cover the development and control of an integrated project plan, managing the risk register and financial tracking of the partners.

Work package 2: 5G Network Design, Commission and Testing

Led by Zeetta Networks and included the design, commission and testing and continuous optimisation of the networks.

Work package 3: Industrial Use Cases

Led by the NCC with a focus on developing the industrial use cases with consortium members as demonstrators to prove value of the 5G network.

The requirements of this work package were delivered via 4 sub-Work packages:

3.1 AR/VR application demonstration using materials and resources from NCC and Mativision

3.2 Asset tracking and Monitoring demonstrations using materials and resources provided by Plataine, Siemens, NCC and Solvay

3.3 Multisensory in-process Monitoring and Analytics using materials and resources provided by Siemens and NCC

3.4 Placeholder for additional use cases – TBD post Phase 1

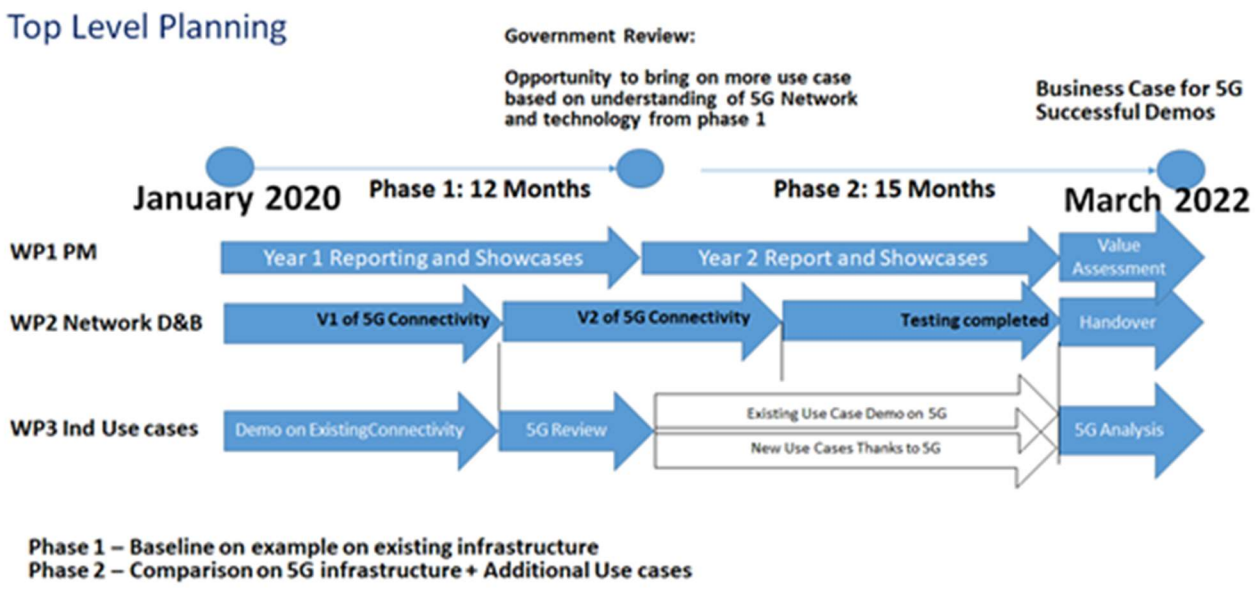

Figure 5: Schedule Baseline

At a top level, the first year will focus on establishing the baseline infrastructure and operational capabilities of the design 5G architecture. Year 2, the networks will be upgrade, extended and optimised and the industrial use cases will be adapted and demonstrated on the available 5G infrastructure and final testing, and demonstrations targeted for January 2022.

Actual

The overall programme ran to schedule and completed in March 2022 as planned. Within the programme there were several high impact issues related to hardware procurement and network stability that resulted in Milestone Nine (9) being delayed by over a month into November 2021 (Planned Oct 2021), the delay however did not result in a loss of quality for the programme.

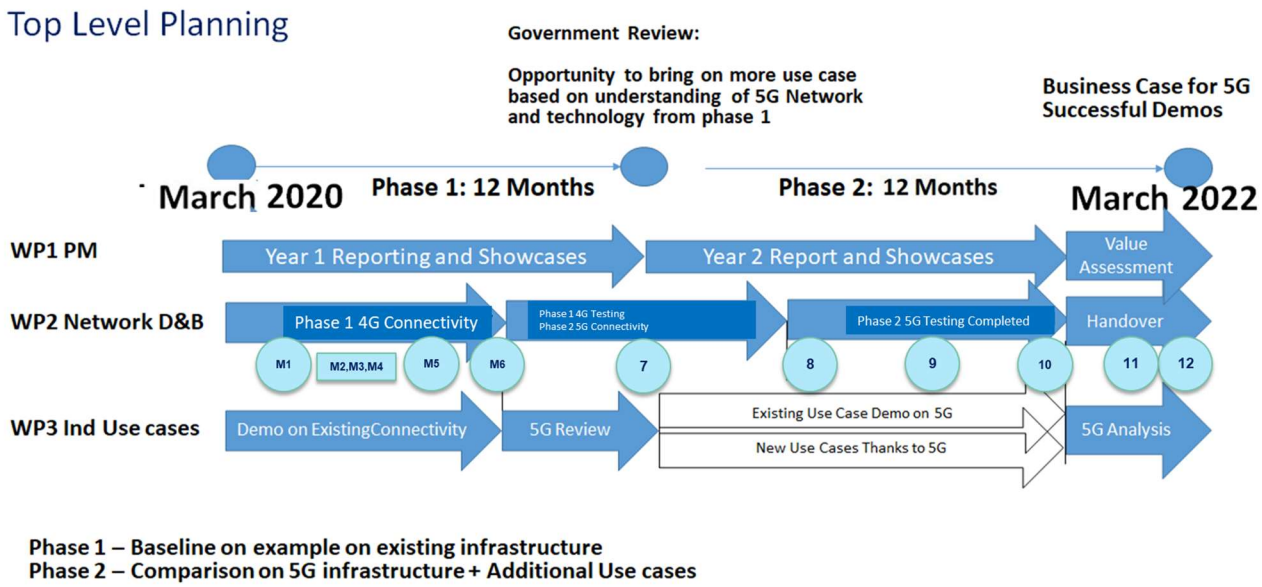

Figure 6: Schedule Actual

BENEFITS & LESSONS

Benefits Realisation

A full benefits realisation was conducted and can be found available for download here: https://www.5g-encode.com/media-and-publications

Lessons Learnt

As part of the benefits realisation lessons learnt were captured, these are found in the above-mentioned BR document and in a summary available for download here: https://www.5g-encode.com/media-and-publications

CHANGES

As part of the project a total of 12 change requests were made and documented in the change log as part of the regular status reporting to DCMS and summarised below

RAG ratings matrix

Red	Very high - materially affects/prevents achievement of the work programme objective or highly damaging impact (e.g., on operational effectiveness or reputation)
Amber/Red	High - significant long-term detrimental effect on achievement of work programme objective.
Amber	Medium - significant short-term damage, and important to outcome of long-term work programme objective.
Amber/Green	Low - affects short term goals within the work programme objective without affecting long term achievement.
Green	Very low - minor and containable impact on achievement of objective.

Req. Number	Description inc. workstream or area	Current Status	Priority
1	Increased our IT overhead costs in Year 1 & Year 2. Moving monies reserved for 5G material spend in Year 2 and also reallocated budget from savings in other categories.	Closed	High
2	Move £225k of budget from year 1 to year 2 due to the following:	Closed	High
3	Change of role for UoB	Closed	Medium
4	Change of role for Telefonica:	Closed	Medium
5	Accession of new partner Accedian to the 5G Encode Project.	Closed	Medium
6	Move all monies, £35,668 within the capital usage pot into materials category. Move £12,500from subcontract pot into materials category.	Closed	Medium
7	Request from DCMS to provide a quarterly status report on the o Network build progress o Use case progress	Closed	Low
8	Changes Requested MS8 – Inclusion of deliverables, D2.3.1, D2.3.2 MS9 - NCC Launch Event – Date Change MS10 – Final Project Report - Date Change Scope change - D3.1.4 will be a feasibility study only.	Closed	Medium
9	Delay to Haptic Feasibility Study	Closed	Medium
10	Return of funds due to programme underspend	In progress	High
11	Change of accountable officer	Closed	Medium
12	£13,500 virement within the University of Bristol's budget	in progress	Medium

Figure 7: Change Log Table

KEY RISKS AND ISSUES FACED

The below table summarises the high impact risks and issues faced by the project a full log was kept in the fortnightly DCMS report submitted to the project lead.

ID	Type	**Description** (inc. consequence & impact on project)	**Countermeasure / Risk response** (inc. contingency)
030	Risk	Covid19: Government advice could escalate to cancel all necessary travel if situation deteriorates. 14-days quarantine for international travellers to the UK will cause disruptions to partners such as Plataine & MatiVision in respective work packages. Impact is to site survey, installation of equipment, commissioning, testing etc. The project will delay until restrictions lifted and will require a replay	Government guidelines followed and tasks and deliverable completed remotely where possible and onsite where practical
043	Risk	Availability of suitable endpoints is limited for Phase 2. NCC have limited technical knowledge to aid market research and supplier engagement.	Workshops and collaboration space facilitated via UK5G, and initial conversations suggest that there are a number of device options that other projects are investigated so we can leverage those conversations. Final outcome was agreement from DCMS to purchase alternative devices
052	Risk	Ofcom don't grant the spectrum licence	Licence awarded with support of DCMS
040	Issue	NCC, IT have limited ability and scope to support project. During detailed discussions and workshops, it has become clear that any dependency on this department will result in delay. However, we are dependent on them for a minimum set of items such as provisioning remote access	Project has interim remote access solution in place and also a permanent solution ordered from Stordis. Project also has phase 1 network now live and external contractor operational support. Further to this NCC have also recruited additional IT resource to assist project. Considering all of this development I am closing this risk.
046	Issue	Telefonica's process to integrate test networks into their Macro network is time consuming and may not meet the project timescales	Telefonica will adopt the existing 4G core at NCC as their 'Proxy' core and the Zeetta MDO product can be demonstrated using this setup. The approach has been agreed by all parties and is now included in the NW design document. Closing risk.

Figure 8: Risk Management Table

OVERALL PROGRAMME PERFORMANCE

Overall, the programme performed well during a period of high uncertainty and disruption caused by the COVID-19 pandemic and the limitations and restrictions put in place to combat the spread, including home working, isolation, and limited travel.

The programme consisting of nine different member organisations worked in a collaborative and professional manner addressing multiple issues associated with researching and transforming manufacturing processes and methods using 5G standalone, ORAN, cellular technology.

The result of the programme was the development, execution, and delivery of 5 x primary key use cases, 4 x supporting use cases and 1 x feasibility study within the manufacturing and engineering environment of the NCC demonstrating the capability or potential capabilities 5G could bring to the industry.

The network splicing use case was not delivered as the neutral hosting network could not be implemented within the project schedule. Network splicing is dependent on neutral hosting. A multi-domain orchestration use case was substituted. Future research is needed to complete this use case.

The use cases showcased at the 5G launch event (Zeetta link and NCC link) held at the NCC in November 2021and attended by Dan Norris, West of England Combined Authority Mayor, with Vassilis Seferidis, CEO, Zeetta Networks, project lead at 5G-ENCODE, and Marc Funnell, Director of Digital Engineering, NCC as the project hosts.

Key stakeholder comment

In the Zeetta Networks news item related to the launch event the following comments are recorded:

Vassilis Seferidis, Founder and CEO, Zeetta Networks, says: "*We are incredibly proud to have hosted this event for our stakeholders showcasing how far the project has come. Launching the network, as planned, in just over 12 months despite the challenges we have faced this past year, is a testament to our partners' hard work. I am honoured to be part of the team building the technology that will revolutionise the manufacturing industry.*"

The NCC's expertise and experience with building, developing, and maintaining testbed environments have been instrumental in keeping 5G-ENCODE on target. The state-of-the-art 5G

testbed now underpins the NCC's Digital Engineering offering to market, providing open technology access to a range of virtual and physical industrial testbeds in a secure environment with expert knowledge and skills.

Marc Funnell, Director of Digital Engineering, NCC, added: *"Manufacturers need to develop sustainable, high-performance products with reduced cost and time to market using low carbon processes which can be accelerated using test beds that exploit the power of emerging technologies such as 5G. What we have demonstrated through our manufacturing industry use cases are the potential efficiencies in product, process and productivity through 5G that can enable innovation."*

In support of the progress that 5G-ENCODE has made, **Dan Norris, West of England Combined**

Authority Mayor shares, *"It's a real privilege to have been invited to launch the industrial 5G network at the National Composites Centre. This is a real vote of confidence in our region's brilliance; it's cutting-edge technology which puts the West of England firmly on the map as a digital powerhouse. The 5G-ENCODE project is testing innovations which could revolutionise the UK manufacturing sector, making it more efficient and sustainable. It will create high-skilled jobs right here in our region and bring in investment. It's good news for the West of England and GB PLC."*

RECOMMENDATIONS

The 5G-Encode project identified many lessons learned. These are broadly grouped as:

- 5G Network and Infrastructure
- Use Case Challenges
- Project Execution
- DCMS processes

Overall the project was successful and delivered on schedule and to agreed budget.

Many of the items identified in this document were worked around, however some remained unresolved. Recommendations for future research and other projects are included where identified. This document is written from the detailed lessons learned documented by each project collaborator. This document highlights learnings that will benefit other projects.

The 5 x manufacturing use cases, 4 x supporting use cases and 1 x feasibility study were completed as planned, lessons learned were captured for the following topics:

- 5G skills and talent
- Equipment availability and maturity
- 5G spectrum and licensing
- 5G performance and resilience
- 5G ORAN and interoperability challenges
- Neutral hosting and slicing
- Edge compute and data transfer bandwidth and latency

Whilst the project achieved most of the defined objectives the cellular technology is relatively immature and costly. These are limitations and constraints that will be overcome as the 5G cellular products mature.

Detailed recommendations are available in the project lessons leant published here: https://www.5g-encode.com/media-and-publications