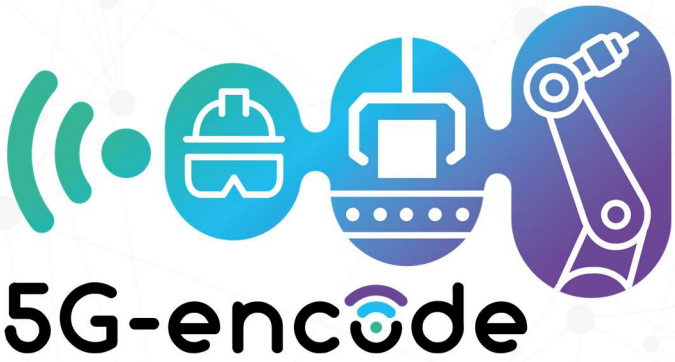

Final Report

Asset Tracking and Neutral Hosting

Feb 2022

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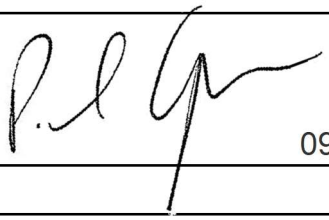
External reviewer	Paul Cooper	 09 Mar 2022
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ABBREVIATIONS

APC	Automated Preforming Cell
AR	Augmented Reality
CTIL	Cornerstone Transmission Limited
eMBB	Enhanced Mobile Broad Band
IoT	Internet of Things
JOTS	Joint Operators Technical Specification
LRI	Liquid Resin Infusion
LSA	Licensed Spectrum Allocation
MEC	Mobile Edge Compute
MMTC	Massive Machine Type Communication
NCC	National Composites Centre, UK
RAN	Radio Access Network
SIM	Subscriber Identity Module
SME	Small and Medium size Enterprises
SWOT	Strengths, Weaknesses, Opportunities and Threats
T&D	Test and Deployment
TUK	Telefonica UK
UoB	University of Bristol
URLLC	Ultra-Reliable Low Latency Communication
VLAN	Virtual Local Area Network
VR	Virtual Reality
WECA	West of England Combined Authority

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 (URLLC/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

This document describes how 5G ENCODE work package 3 was delivered, and the use cases were developed and executed, and the contribution consortium members made in delivering use case 2 (AR/VR) and use case 5 (Neutral Hosting and a possible O2 Interconnect opportunity).

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 it was 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 RAN solution that would be managed by 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 was not provided 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.

INTRODUCTION

As per the collaboration agreement (Appendix B), TUK's role in 5G Encode was to assist in Test & Development spectrum acquisition, network design and evaluation of technology vendors.

This was however revisited later to as follows.

- Consultancy - Spectrum T&D licenses, to help & assist in network design and evaluate technology vendors.
- SIMs to allow the use of TUK Public O2 4G / 5G for the external route testing from UoB to NCC.
- Possible adoption of the private network or joining of the neutral hosted solution at the end of the project (RAN connection to O2 core via VLAN) to ensure a smooth transition ideally needs to be Ericsson or Nokia.

Following was out of scope:

- No external Private Network Deployment/Coverage beyond NCC premises.
- No external Network Multi Domain Orchestration (MDO) beyond NCC premise.
- Telefonica had not yet deployed a public 5G SA core, therefore, testing of MDO was not possible within the life of the project.
- No connectivity to the TUK public core of any test network. Due to the complexity of integrating a private network in a public network. Something 5G DRIVE looks to solve.
- Everything that is not explicitly covered above in the opportunities is out of scope.

Figure 1 below details the work packages and use cases where TUK contribution was planned in the 5G ENCODE project. TUK's involvement was planned in work package 3 to enable parts of use cases 2 and 5.

Usecase category	Usecase #	Usecase	Details	TUK Involvement
Use Case 1 – AR/VR	WP3.1.1	Application 1: VR 360 Video training	Training video streamed to remote students in real-time to give a real-world experience.	No. TUK already participating in similar usecases in other POCs
	WP3.1.2	Application 2: AR training	3D overlays in real space to guide the user in real world scenarios.	
	WP3.1.3	Application 3: VR and haptic controlled robots	Remote control of off-site robot arm. VR and Haptic interfaces for the real-time user experience.	
Use Case 2 – In-building & Outdoor High value manufacturing Asset Tracking	WP3.2.1	Indoor @NCC-HQ and @NCC-I	Visibility of asset location within factory boundaries, the Continuous track of time sensitive conditions, Maintaining traceability and pedigree of assets and Establishing asset-equipment relationship.	Yes, TUK is providing spectrum for indoor use
	WP3.2.2	Outdoor @Telefonica/O2 Public Network	Asset location outside factory boundaries and continuous tracking, Initiation of Material Passport, Enablement of in process quality control technologies, and Recyclability and reuse of assets.	Yes, TUK will be supporting outdoor tracking
Usecase category	**Usecase #**	**Usecase**	**Details**	**TUK Involvement**
Use Case 3 – Preparation for manufacturing sensor deployment	WP3.3.1	Closed Loop Manufacturing in LRI (Liquid resin infusion)	The current monolithic control system will be disaggregated, split over 5G wireless connectivity, partly virtualized in a virtual machine hosted on project's MEC/compute platform. These steps will enable the insertion of an AI/ML based decision engine and a visualisation application.	No
	WP3.3.2	Automated Preforming Technology (APC)	5G transformation of the ProFactor Verification End Effector. It is a commercially available verification system that integrates with a robot and features sensors. These sensors are coupled to a high-powered PC, which hosts the ProFactor application for the analysis of the sensor information for accurately detecting defects.	No
Use Case 4 – Toshiba	WP3.4.1	TBC		-
Use Case 5 – Neutral Hosting and O2 Interconnect	WP3.5.1	NCC providing service to MNO (for MNO's customers)	Adoption of the private network or joining of the neutral hosted solution at the end of the project	Y
	WP3.5.2	MNO providing service to NCC (linked to WP3.2.2 Outdoor Tracking)		Y

Figure 1: Work Package 3 Use Cases where TUK planned to contribute

5G ENCODE PHASE 1

In this phase a 4G cellular private network was implemented in two separate NCC premises named NCC and NCCi. Each industrial use case executed within the constraints of the 4G technology to create baseline network performance measures and understand design changes needed to be successful in a 5G cellular deployment. TUK had minimal involvement in phase 1.

The Phase 1 network was managed as separate domains, each associated with a location. The following domains were provisioned:

- NCC Building (NCC): A fixed deployment, with distributed access to each of the project locations, but with a centralised infrastructure, managed by NCC and visualised using Zeetta's solution.
- NCCi Building (NCCi): A portable deployment, located in the relevant manufacturing cell, managed locally by Zeetta, and visualised in their solution.

The Phase 1 network was to be a subset of the Phase 2 deployment. Phase 1 was designed to test use cases in a cellular environment and identify where processes in the use cases needed to change and identify limitations of the 4G LTE cellular network. The manufacturing use cases exercised in phase 1 were as follows:

- Use Case 1 – Distributed Training. In this use case there were two parts to the training: a virtual reality and augmented reality training. For the virtual reality training session, a camera located in the NCC workshop was used by the trainer to deliver content to a class of trainees in other parts of the NCC. The training session was delivered using virtual reality 360-degree camera with two-way interactive component for trainees to ask questions of the trainer. The virtual reality training was followed by an augmented reality trainee exercise to assemble a component ready to be used in the liquid resin infusion use case.

- Use Case 2 – Asset Tracking. In this use case RFID sensors were deployed around the tracking area. Each RFID sensor used the private cellular network to transfer location of detected RFID tags to the central hosting platform in the Enterprise LAN. In Phase 1 of the project the RFID sensors detected the transition of passive RFID tags entering the building and when passing specific locations within the building. Materials and assets to be tracked were fitted with a passive RFID tag that triggers the sensor when passing. The use case tracked materials from the Solvay supplier factory, through the public network, arrival at the NCC and then inside the NCC location. The use case also tracked tools inside the NCC location.

- Use Case 3 – Ultra low latency in production processes. In this use case two production processes were executed to demonstrate the business case for 5G: Liquid Resin Infusion (LRI) and Automated Preforming Cell (APC). Whilst each industrial process has different network performance needs each needed to collect data form IoT sensors, transfer the data to a mobile edge compute (MEC) function and receive change commands returned.

The outcomes of each use case being exercised are recorded in the detailed report for each use case.

The aspects of phase 1 where TUK had offered to help:

- Spectrum license requests
- Consultancy
- Public network SIM card allocation

Licenses to radiate 4G in the LTE spectrum were acquired from OFCOM by NCC. The project informed TUK that support for Use Case 2 (Asset Tracking) out of building was not needed, this was a decision by the project to ensure the planned timescale and budget was met. As part of use case 2 (Asset Tracking) 2 SIM's were provided to the project team for testing out of factory tracking.

5G ENCODE PHASE 2

In this phase a 5G Open RAN (ORAN) Standalone (SA) cellular network was implemented in two separate NCC premises and the Millennium Square in Bristol. Each industrial use case was executed with the network performance and updated application performance characteristics measured. In phase 2 the Millennium Square location was used to exercise and show case the VR and AR use cases in a public space using an outdoor Nokia solution provided by the University of Bristol.

- NCC Building (NCC): A fixed deployment, with distributed access to each of the project locations, but with a centralised infrastructure, managed by NCC and visualised using Zeetta's solution.
- NCCi Building (NCCi): A portable deployment, located in the relevant manufacturing cell, managed locally by Zeetta, and visualised in their solution.
- UoB 5G Testbed in Millennium Square, Bristol: An extension of the existing deployment, managed by existing UoB systems.

The Phase 2 network extended the Phase 1 network to include 5G RAN. The network design included a shared Home Subscriber Server (HSS) hosted by the 4G network being reused to provide 5G network access. To separate data service traffic for subscribers different Access Point Names (APN) for 4G and 5G were used. The manufacturing use cases were repeated in phase 2 as follows:

- Use Case 1 – Distributed Training. In this use case the quality and latency of the video stream and two-way interactive service in a static situation were the success criteria for the deployed 5G.

- Use Case 2 – Asset Tracking. In this use case coverage, uninterrupted data transmission and mobility were success criteria for the deployed 5G.

- Use Case 3 – LRI and APC production processes. In this use case latency and high-volume data transmission in a static situation were success criteria for the deployed 5G.

The results of each of the above use cases are captured in the detailed final reports produced in separate documents.

TUK was asked if they would be prepared to support use case 2 as materials left the supplier facility travelled through the public network and arrived at the NCC (WP 3.2.2 –

Out of factory Asset Tracking). The Solvay final report documents 5G cellular in a controlled materials factory, the NCC final report documents the 5G cellular enablement of asset tracking in a production environment.

The original intention was to use TUK 5G Standalone (SA) public network, including a selection of outdoor sites covering the surrounding areas of NCC premises, providing better positioning accuracy outdoors than possible with LTE. Hence, continuous tracking of materials transfer from the private network in the supplier facility (Solvay premises) onto the public network support (TUK) and then into a destination private network (NCC).

However, due to internal roadmap and 5G SA readiness timelines, TUK proposed using an isolated private network with 5G SA core and outdoor RAN solution for the 5G ENCODE project to reduce the requirements needed to create a neutral hosting environment (options proposed specified in Appendix A). Unfortunately, this proposal created a delay to the project schedule with that would affect multiple collaborators and a cost that exceeded the planned project budget. To attach and host a private network from a public network needed processes to be agreed to manage; security, RAN technology characteristics, users and entitlements and inter network billing, these were not within the agreed scope of work for TUK. The project team decided to use RAN from Airspan and a DRUID Core and forgo public network hosting. Out of office asset tracking used a GPS based tracking alternative solution.

WP3.2.2 – Out of factory Asset Tracking

A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis to support Use Case 2 (WP3.2.2 Asset Tracking) was completed. As a result the alternative GPS based solution was selected to deliver the 5G network in Q4 2021 and maintain the launch planned for 30 November 2021.

5G DISCUSSION

TUK does not have ability to deploy an outdoor private network, in the Vodafone deployment area of the country, as it restricted by the terms of its Joint venture (CTIL). TUK offered public sims cards as a viable alternative. This would allow for the transfer of users from the indoor private network to O2 public outdoor network as required by use case 2 for 5G Encode Phase 2 was not completed due to the project's decision to de-risk the timelines.

This significant increase in scope for TUK required significant additional budget approval, approval was obtained for an inbuilding solution. The project team discussed this with the engineering team at Zeetta and determined it was not going to be possible for them to take on the extra work of integrating the Nokia solution within the budget and timescales of the project. Various options were discussed to understand whether other activities could de-prioritized to enable the TUK proposal, but it was determined by the project that was not going to be possible.

Adoption of the 5G Encode RAN, and integration with TUK Core following Neutral Hosting model was not completed. It was discussed with UoB and Zeetta that they will go through the Joint Operators Technical Specifications (JOTS), and that this is Telefonica's preferred approach for Neutral hosting (though the specifications only cover indoor LTE and doesn't address outdoor deployments, 5G or distributed RAN architecture). Adaptation of NH solution to include distributed RAN and 5G was not aligned to project's timelines.

To improve the ability to adopt and use neutral hosting in a public network operator environment more time is needed in project schedules for interoperability, licence obligations and security testing of products not in the approved mobile network operator catalogue e.g. new core and RAN elements.

The activities needed to adopt integrate private and public networks using JOTS need more work than was planned for in 5G ENCODE.

It is recommended that for future projects a SWOT is conducted very early in the project to give the public mobile operator time to plan any needed integration.

It is for this very reason TUK now Virgin Media O2 put for forward a proposal called 5G DRIVE as part of the DCMS FRAN Competition, to allow for a simplified model of adoption. Allowing private networks to be simply integrated into a public network.

With the approved it is hoped that the integration issues; staffing, OPEX, CAPEX budget, Security, Regulatory requirements and Public Network Service Protection encountered in this project will be a thing of the past.

More information on project 5G Drive can be found here https://uk5g.org/discover/5G-projects/5G-Diversification-Projects/5g-drive/

APPENDIX A

The following deployment options were considered during the initial planning.

1. TUK temporary mobile private network deployed at the NCC headquarters building, with coverage contained within the building itself.

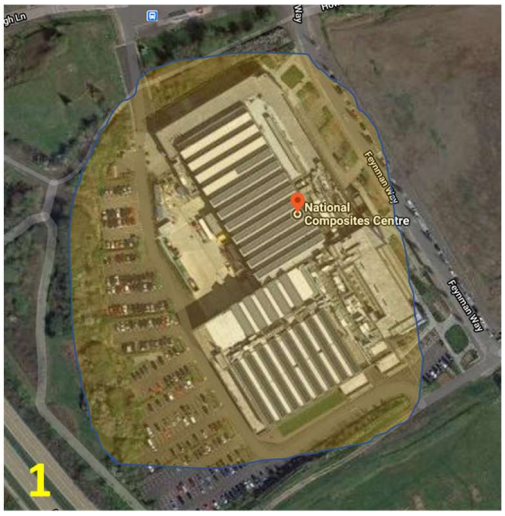

Figure 2: MPN deployment at NCC headquarters

2. TUK temporary mobile private network deployed in NCC headquarter building with outdoor coverage transfer between NCC and TUK public network.

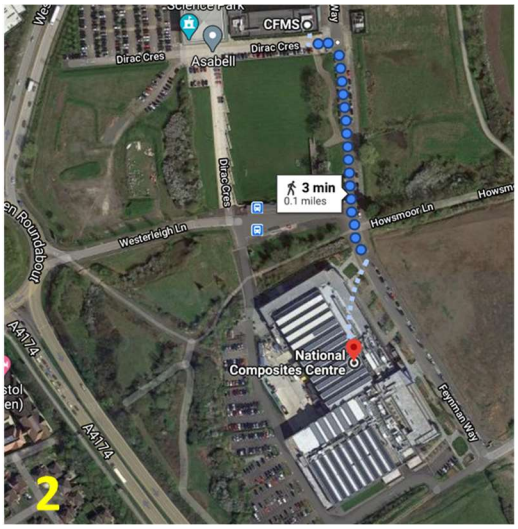

Figure 3: TUK MPN deployment at NCC premises with outdoor coverage by CFMS

3. TUK temporary mobile private network deployed at NCC and NCCi premises with outdoor coverage between both premises provided though TUK public network.

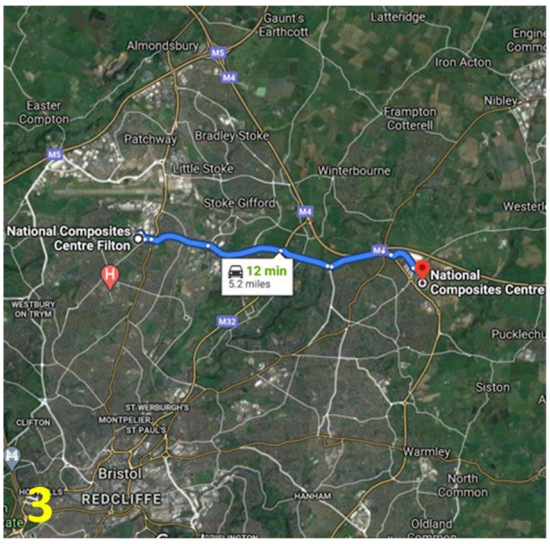

Figure 4: TUK MPN's connected over public network

APPENDIX B

Telefonica 5G spectrum management plan in case 5G standalone operation needed TUK spectrum or with LTE anchoring in case of Non-Standalone operation. In the event that Licensed Spectrum Allocation (LSA) spectrum needed to be used in the range 3.8-4.2 GHz this would be subject to TUK internal clearance.

Option	RAID	Advantages	Caveats
1-3) TUK deploys a temporary 5G SA (option 2) based private core with outdoor RAN coverage: • contained within NCC premises or between NCC and CFMS • using TEF 5G Frequency or LSA from Ofcom • PLMN ID 23402 or 999 (or use specific SUPI range) to avoid TUK customers attaching to the network	• **A1**: TUK will be accountable to manage this network (assumed turnkey solution from TUK vendors) • **A2**: NCC/Zeetta will apply and use LSA spectrum (i.e. not use TUK spectrum for their indoor private network) • **A3:** Will need SIMs with PLMN ID 999 or 23402. It is assumed that SIMs (or SIM writer) will be provided by this TUK Private Network vendor. • **A4**: Interference to TUK Macro network will be controlled by limiting power of the PV NW RAN • **A5:** This will be a release 15 SA network (Core and RAN) • **R1**: Once the Macro network is 5G enabled in Bristol, there is a risk of interference to this TUK provided private network outdoor coverage – Probability is Low. Regardless, Martin Gilbert (Regional Radio Manager) will need to be kept in loop. • **R2**: Higher than committed costs – Probability is High • **D1:** Devices used by 5G Encode project may need to support 23402 and/or 999 PLMN IDs; and 5G SA. • **D2:** Approval from Beacon partnership team.	• 6-12 months POC type deployment including turnkey deployment, integration and support by the vendor, hence an isolated deployment from TUK perspective with no need for integration with TUK network. • Assumed TUK is responsible to run and manage this network, then no need to apply for T&D licenses, which saves time and effort. • Providing ability for the project to test MDO and indoor/outdoor asset tracking.	• Additional equipment and resourcing cost than committed by TUK initially. • The project will have dependency on this network deployment by TUK preferred vendors, which might lack in features or present interoperability issues with the NCC deployed Druid Raemis Core and IP Access RAN.

Figure 5: TUK spectrum management plan