DSIT 5G FUTURE RAN COMPETITION

PROJECT - 5G DRIVE

Diversified oRAN Integration & Vendor Evaluation

Final Report

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Foreword

This document marks the closure of the 5G DRIVE project, and details the comprehensive efforts of all the partners. Our project has been a collaborative effort, bolstered by the contributions of our key partners: Wavemobile, Ori, Cisco, WMG University of Warwick, and VMO2.

Companies behind the consortium:

1. **Wavemobile** - Provided the test core & radio networks and the roaming SEPP/IPX/N32 interface, the system essential for the deployment and evaluation processes.
2. **Ori** - Delivered the Multi-Access Edge Compute (MEC) for system testing, integrating the 5G core network, including SEPP. This component, commonly referred to as Mobile Edge Compute, was pivotal in phase 3 of our project.
3. **Cisco** - Deployed its 5G core to showcase critical security and scaling capabilities and supplied private enterprise firewalls to enhance our deployment.
4. **WMG** University of Warwick - Conducted the security review of the system design, offering insightful recommendations for future implementations.
5. **VMO2** - Provided the project and financial management, ensuring smooth coordination and execution of the project phases. They were also responsible for the public relations and communication of the project.

This project closure document is a comprehensive and conclusive record of our achievements, challenges, finances, and outcomes throughout the 5G DRIVE project. It will be issued once, at the end of the project, to encapsulate the entirety of our efforts and results.

We extend our gratitude to all partners for their dedication and expertise, which have been instrumental in achieving the goals of the 5G DRIVE project. and finally to DIST for having the belief in what our project could deliver.

David Owens

5G Drive Project Lead

28th June 2024

Executive Summary

The “5G DRIVE” project, funded by the Department for Science Innovation & Technology (DSIT) under the Future RAN Competition (FRANC) programme, is set to revolutionise the integration of Private Networks with UK Mobile Operators' Public Networks using the SEPP/IPX N32 platform, using modern internet protocols. This initiative leveraged 5G technology to streamline and enhance connectivity, fostering a more inclusive and efficient network ecosystem.

The name DRIVE stood for Diversified RAN Integration & Vendor Evaluation. It encapsulated our mission to urge the mobile industry towards diversification, and ‘drive’ as defined by the Oxford dictionary, which emphasises moving in a specified direction based on sound reasoning and demonstration. Diversifying the supply chain was essential to creating a healthy, sustainable, and cost-effective radio access network ecosystem.

The core objective of the 5G DRIVE project was to provide a straightforward method for integrating private indoor networks into public 5G mobile networks. This integration was achieved seamlessly, utilising a common, well-understood interface that minimised the need for significant operator engagement, resources, or costs.

Private indoor networks not provided by tier 1 vendors face substantial hurdles when integrating into Mobile Network Operators (MNOs) networks. These challenges included significant resource demands, high infrastructure investment costs, and potential security risks. Additionally, there were operational concerns such as ownership, training, and regulatory responsibilities.

Connecting Private Networks to Operators' Public Networks was particularly crucial for Small to Medium Enterprises (SMEs) aiming to adopt 5G for their wireless communication needs. MNO integration was vital for various reasons, including spectrum allocation, device compatibility, service availability, operational support, and extending coverage beyond the premises.

This document outlines the consortium's vision for the 5G DRIVE project and details the accomplishments of the three-phase project and its final extension phase. Our approach focused on designing, testing, building, and demonstrating the SEPP/IPX N32 platform's capabilities to transform private and public network integration.

By achieving these goals, the 5G DRIVE project set a new standard in network integration, ensuring that private networks could seamlessly and securely connect with public 5G networks, ultimately benefiting businesses and consumers alike.

In the project extension we had the opportunity to deliver 31 small cells to the coast of Wales and Scotland, as well as iconic locations in the UK too. The small cells designed & built in the UK provide voice and data service to remote rural locations, as well as those all-important 999 calls.

Commented [S(1]: Changed from 32 to 31 sites

Ant Timson CTO Wavemobile - Technical Lead

28.06.2022

1. Introduction & Scope

1.1. The 5G DRIVE

The 5G DRIVE project is a proof-of-concept trial looking at how SEPP/IPX/N32 might be incorporated into future mobile network architectures, to allow the integration of Private networks in a seamless, secure and low cost way.

The new 5G NR roaming architecture incorporates the Secure Edge Protection Proxy (SEPP), a critical component that ensures secure and scalable interconnectivity between 5G networks. SEPP is an integral part of the 5G standard roaming architecture interface. By integrating an Internet IPX service, operators can inspect and modify traffic in transit, applying necessary security measures before it reaches the MNO network. This approach maintains end-to-end confidentiality and integrity for all 5G interconnect roaming messages between source and destination networks.

The 5G DRIVE solution further enhances this architecture by offering a scalable, cost-effective, and agile method for integrating Private Networks (PNs) into Mobile Network Operators (MNOs). Traditional methods of integration can take months and incur prohibitive costs too, but the 5G DRIVE solution meets all stakeholders' requirements more efficiently, enabling rapid deployment and reduced operational costs. In summary a key innovation that 5G Drive brings is the use of a standardised (SEPP) interface towards PNs which avoids bespoke integrations, and this delivers both scalability and cost efficiency.

It is also hoped that the project will encourage an ecosystem to support this opportunity going forward. Allowing us to deliver great experiences for our customers, and to provide a positive news story for 5G that is both practical & realisable.

1.2. The 5G DRIVE project consisted of 4 phases at a number of locations.

1.2.1. Phase 1

During the first phase, the project established an end-to-end test system at the Wavemobile 5G test lab in Oxted.

The test system was based on the Quortus 5G Software Defined Network with Network Function Virtualisation and the next generation Core architecture, with the radio access network from Amarisoft, which is a 5G SDR radio. The test network consisted of two cores and one radio network, and the project used this system to demonstrate connectivity between the two cores via the SEPP IPX N32 c & f interfaces.

The tests validated the connectivity over the SEPP roaming interface and specifically the JWE (JSON Web Encryption) N32c message protection and the IPX JWS (JSON Web Signatures) N32f for message modification or deletion. Tests were conducted on the N32 message modification to understand the extent of this capability.

Finally, we ensured that the system could carry user plane traffic, replicating normal customer behaviour and use cases.

This proved and demonstrated the capabilities of the SEPP/IPX/N32 roaming interface, specifically focused on the security rule set functionality to deliver carrier grade security. Testing looked at the processes and security executions across all various components.

1.2.2. *Phase 2*

Ori deployed a 'containerised' Quortus core Network at the Harwell site to simulate the O2 public core network. This established a two-location network, connecting Wavemobile's laboratory in Oxted to the VMO2 core at the Harwell lab. Enabling the project to test the end-to-end performance of the SEPP roaming interface at a distance.

CISCO started deployment of their the p5G core, which during phase 3 will demonstrate some key security & scalability capabilities, such as; device authentication, and private enterprise firewalls.

Finally, the performance, security, and capabilities of the system were measured using the same test metrics that were applied in Phase 1, while also developing Use Cases in preparation for Phase 3 testing.

1.2.3. Phase 3

During phase 3 the project will work with three universities, namely; University of Surrey, University of Glasgow & the University of Warwick to introduce an instance of the DRIVE private network solution at each location. This will allow the project to deliver three on premise corporate network demonstrations of a 5G NR SA Private Indoor Network leveraging MEC and using the SEPP/IPX/N32 interface architecture developed and tested in this project.

The project aims to showcase the ease of use and security of the SEPP roaming interface by utilising the insights gained from previous phases to demonstrate a scalable method for delivering private networks through a containerized Multiple Access Edge Compute solution on low-cost servers. Additionally, CISCO's P5GN solution will be integrated with the VMO2 Lab at Harwell, to simulate a corporate private network to test the concept of an intermediate service provider or third-party aggregator.

It is important to note that the university will be connected to a replica of the VMO2 public core network, specifically a 'Quortus Core in the VMO2 Lab, which was utilised for testing in phases 2. The same test metrics used in the earlier phases will be employed to evaluate the system's performance, security, and capabilities.

1.2.4. Phase 4

During Phase 4, the project successfully delivered 31 sites to remote rural locations, with 5 in England, 21 in Wales, and 5 in Scotland. These sites utilised four main components: the Cellxica M3Q radio, a Starlink backhaul, Ubiquiti modem and router, and Kerlink LoRaWAN gateway, along with sensors. The aim was also to connect these sites to MNO cores. While we intended to use SEPP/N32c, which employs modern internet protocols, to interconnect the networks, we were forced to compromise with the Joint Operators Technical Specification (JOTS). This compromise makes future funding models

unsustainable unless the operators agree to pay an annual licence fee for the coverage delivered.

In the interest of proving the model technically, we agreed to this compromise and plan to revisit the funding model after the project's completion. However, this situation clearly illustrates the MNOs' desire to maintain control over entry into this closed market, which highlights a need for change if we want to encourage new entrants and vendors.

2. Locations

Throughout the duration of the project, a variety of remote and rural locations across the UK were selected to host the deployment sites. These locations were strategically chosen to address coverage "Not Spots"—areas where mobile and internet connectivity is minimal or non-existent. The aim was to bring reliable connectivity to these underserved areas, improving communication capabilities for both residents and visitors.

Some of the notable locations that were part of the project include:

- **Buttermere, Cumbria** - A picturesque village in the Lake District known for its stunning natural beauty.
- **Gatesgarth, Cumbria** - Located near Buttermere, this remote area is popular among hikers.
- **Honister Slate Mine, Cumbria** - A historic site in the Lake District offering unique tourist attractions.
- **Vatersay Community Centre, Scotland** - Serving the island of Vatersay, this site enhanced local connectivity.
- **Barra Airport, Scotland** - The only airport in the world where scheduled flights land on a beach.
- **Loch Ossian Youth Hostel, Scotland** - A remote, eco-friendly hostel located on the edge of Loch Ossian.
- **Corrour Station, Scotland** - One of the most remote train stations in the UK, providing vital transport links.
- **Glenlyon Tea Rooms, Scotland** - A charming tea room in one of Scotland's most secluded glens.

Additionally, the project was supported by several key partners, each based in different strategic locations across the UK:

- **Wavemobile** - Based in Oxted, Surrey.
- **Virgin Media O2 (VMO2)** - Based in Reading and Harwell in Oxfordshire.
- **Cisco** - Located in the City of London.
- **Ori** - Based in Vauxhall, London.
- **University of Warwick** - Located in Coventry.
- **University of Glasgow** - Based in Glasgow, Scotland.
- **University of Surrey** - Located in Guildford, Surrey.

These locations were crucial in demonstrating the project's ability to deliver enhanced connectivity in challenging and remote environments, ultimately bridging the digital divide in areas that had previously been left behind. The collaboration across these diverse locations also highlights the breadth of expertise and resources that were brought together to make this project a success.

2.1. In Scope

Please note that this Project Closure Document exclusively covers Phase 3 of the 5G DRIVE project.

So in scope;

2.1.1. A more complete description of the SEPP roaming architecture and functionality
2.1.2. The deliverable for phase 3 are;
  2.1.2.1. 5 x core networks connected via SEPP/IPX/N32 interface. Implemented within a containerised solution of the 5G NR SA NGC system, from Quortus, with the Harwell Lab replicating the VMO2 5G NR Public Network.
  2.1.2.2. Deployment locations; Warwick, Glasgow, Surrey, Oxted & Harwell.
  2.1.2.3. 5 x Amarisoft 5G NR SA Radio Access Networks, RAN, so that calls and data sessions can be made.
  2.1.2.4. 10 x OnePlus Handsets so that the user interface and subscriber use cases can be tested.
  2.1.2.5. 1 x CISCO's P5GN cloud network solution, for testing scalability of the project solution, and the device authentication process
2.1.3. The general security requirements will be managed by the project team.
2.1.4. The detailed security analysis will be managed separately by WMG University of Warwick as it's a standalone project.
2.1.5. The details of Demo 3, planned for June 16th at the Harwell location. utilising all of the Harwell Labs assets for example CAV, & drones.
2.1.6. The deployment of 31 sites across remote rural areas, in England, Wales and Scotland.

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2.2. Out of Scope

This PCD will not include details;

2.2.1. 5G Voice calls may be out of scope, as requires the implementation of an IMS platform,

2.3. Document structure

The document is structured into a number main sections:

2.3.1. **Executive summary** - This section provides a general overview of the project.

2.3.2. **Introduction & Scope** - Defining the project's technology components, its concepts & technology, the aims of the project, as well as defining what is in and out of scope for this document.

2.3.3. **Phase 1, 2, 3 & 4 deliverables** - Describes the list of things, and jobs to be done, that need to be delivered by this part of each phase of the project.

2.3.4. **Project vision** (David) - provides a description of the desired ultimate outcome of the project once it has been completed.

2.3.5. **High-level design**- this section describes the **high-level design** in terms of the architecture used for the project**.** Providing diagrams, and list of deliverables, detailing the envisioned hardware and software to be used, it is written using non-technical language to improve readability.

2.3.6. **End to End Testing Programme-** Testing of all the components that make up the delivery system. April to organise, then physical testing in May & and demo in June at Wavemobile Oxted 5G Innovation

2.3.7. **Customers and other stakeholders** - This section will identify stakeholders, think about whom this project will affect, both system providers and consumers, positively or negatively, and who might have a vested interest in the project to succeed.

2.3.8. **5G Network Architecture Wave & O2** - This section will describe the technical solution for this project. In terms of a specification, or a "design blueprint" if you will, for both; Hardware, & software.

2.3.9. **Mobile Edge Compute** - This section will describe the purpose of the Mobile Edge Compute, MEC, which will provide a number of functions. Primarily related to implementing a 5G NGC as SDN/NFV containerised solution in the Harwell lab and the four corporate sites, the main tasks would be; the implementation of a facsimile of an O2 public network, and on premise corporate core networks, encryption capabilities, and testing secure N32 interfaces. Each private network (VPLMN) will be enhanced with a local MEC capability to deliver additional use cases, and supporting RAN from various vendors with local breakout support**.**

2.3.10. **Network Hardware & software (**Jim & Ali**)** - This section will provide the **specification** of the **mobile network's** physical components and their functional connectivity and configuration, the operational principles and procedures, as well as communication protocols used. Core connectivity.

2.3.11. **Network Security** (Gregory & Nabil) - This section will detail the security requirements for this part of the project. It will include a risk summary and mitigation plan.

2.3.12. **Lesson learned (**Matt**)** -

2.3.13. **Target KPIs requirements (**Dez**)** - This section will cover all of the KPIs for end to end Network design, Functionality & Application performance. Including KPIs for Network, System & Use cases.martin

2.3.14. **Benefit realisation (**Dez**)** - This section will describe how we will track our 'use case' definition process and in life management & evolution.

2.3.15. **Data flow diagrams (DFD) and data format matrices**- The DFD section will provide a graphical representation of the "flow" of data through an information system, required to provide the services. It helps provide an understanding of the data processing steps required to deliver required data. It will be a preliminary step that we will use to create an overview of the system.

2.3.16. Achievements

2.3.17. Project Sustainability

2.3.18. **In Remote Corporate network Design** - This section will cover a plan for the Corporate on premise design at each university, which will be completed as part of the Phase 3 delivery. The in premise design will be made available for review.

2.3.19. **Document summary & next steps** - we have decided that the final demonstrations will take place in several corporate premises. The event will be a multi day event, the project will provide a comprehensive plan for this activity in December 2022

2.4. The Aim of Phase 1, and the demo 1 - complete.

During the first phase, the project established an end-to-end test system at the Wavemobile 5G test lab in Oxted. The test system will be based on the Quortus 5G Software Defined Network with Network Function Virtualisation and the next generation Core architecture. The Amarisoft 5G SDR radio. The 5G test network will consist of two cores and one radio network, and the project will use this system to demonstrate connectivity between the two cores via the SEPP IPX N32 c & f interface. A 5G Security Edge Proxy (SEPP) is required to protect traffic crossing a security domain boundary.

2.5. The Aim of Phase 2, and the Demo 2 - complete.

The phase 2 Trials ran from July 2022 to December 2022 - located at both the O2 lab at Harwell & Wavemobile Lab in Oxted. During phase 2 of the project, we established and tested an Ori containerised Quortus core Network at the Harwell site with a simulated corporate customer with 5G PN & MEC. The SEPP Roaming concept was tested end to end between Harwell lab & Wavemobile lab in Oxted.

During Phase 2 Cisco deployed a private 5G network solution with both edge core and Airspan Radios residing at Harwell and the management function delivered by Cisco Cloud Services.

2.6. The Aim of Phase 3, and the Demo 3 - complete

The phase 3 trials for the project will run from January to September 2023. This phase of the project will consist of corporate customer 'on-premise' integration trials and vendor evaluation. The project will aim to deliver three corporate network solutions, testing the SEPP roaming concept in a realistic corporate network, with customer use cases. During this phase of the project we would welcome collaboration with any FRANC projects wishing to test their private network solutions.

2.7. The Aim of Phase 4 - complete

Phase 4 of the project represented a significant expansion of our initial objectives. In this phase, the project team ambitiously set out to deploy a network of up to 30 sites in remote rural locations identified as coverage "Not Spots" (NS). These are areas where mobile coverage is either extremely limited or non-existent, posing challenges for residents and visitors alike.

The primary aim of Phase 4 was to bring reliable connectivity to these underserved areas, leveraging the Wavemobile/Cellxica solution, which was ideally suited for such challenging deployments. Our goal was not only to provide basic mobile connectivity but also to enhance the digital infrastructure by integrating Wi-Fi, LAN, and LoRaWAN services wherever possible. This comprehensive approach ensured that local communities and visitors could stay connected with family and friends, access the internet, and, most importantly, make those critical 999 emergency calls when needed.

We are pleased to report that we successfully completed the rollout, surpassing our initial target by deploying 31 out of 32 possible sites across the UK. This included 5 sites in England, 5 in Scotland, and 21 in Wales. This part of the project concluded on 31st July 2024. It has been an epic journey, and we are proud to share these accomplishments, which have made a tangible difference in improving connectivity for remote rural communities across the country.

3. Deployment - Project & Technical Management

As a project team we have chosen the Google Drive tool. Tasks will be defined and managed via weekly meetings, emails with documents stored on Google Drive that will allow us to work as an 'effective' coordinated team. Matt Powell was appointed as the project manager, after Ryan John left the project in January of 2024, with David Owens as the Project Lead.

The project has also set up a technical working group, this will help us deliver the technical elements of the project. The members of the technical working group are; Wavemobile, Ori, CISCO, VMO2 with Jim Croal from Wavemobile being appointed as the Technical working group lead.

The project also had a dedicated team focused on communication and outreach, aiming to provide insight into the project and its achievements. This activity was coordinated by Matt Powell, Vicki DeBlasi, and Adam George. Unfortunately, there was some disappointment as progress in this area stalled after our showcase event in October 2023, and the anticipated communication efforts did not materialise as expected. But then on 19th & 20th March we were featured on ITV (Wales), talking about remote rural coverage thanks Adam George

3.1. Other tools

All project documentations, data, and multimedia will be stored on the project's Google Drive, each document will be uniquely numbered and logged in a spreadsheet, and the project directories will be clearly named.

3.2. Project milestones

The delivery of this project is captured in the 3 phases, and 3 demonstrations and a final 4th extension phase :

3.2.1. **Phase 1** - 1st January to the 30th June 2022 - Delivery of HLD 1 March, Project Security Document April, & Benefit Realisation Document. Complete

3.2.2. **Demo 1** - 13th June 2022 - Technology Demo at the Wavemobile lab. Complete

3.2.3. **Phase 2** - 1st July to 30th December 2022 - End 2 End Testing Phase Oxted & Harwell, Completion of the HLD2 in June 2022. During this phase we will demonstrate the overall aspect of the solution; this includes SEPP/IPX/N32 and customer use cases.

3.2.4. **Demo 2** - 15th December 2022 - Small Scale Demonstration of the architecture across the two labs at Oxted & Harwell to demonstrate the remote communication capabilities of the solution.

3.2.5. **Phase 3** - 31st December 2022 to 30th September 2023 - And will culminate with on premise testing with University Corporate Networks.

3.2.6. **Demo 3** - June 2023 - A visit to all University Corporate Networks, virtually or in person, to show their Private networks in action, followed by a press day at the O2 Lab in Harwell utilising the lab assets CAV, Drone & 5G Networks.

3.2.7. The final Phase 4 had 4 milestones, running from 1st October 2023 to 31st July 2024. namely; MS26 :: Site Installations 1 (8), MS27 :: Site Installations 2 (12), MS28 :: Site Installation 3 (10) & MS29 :: Security Analysis Phase 3

4. Project Vision

4.1. 5G DRIVE - Private Network Integration

The primary goal of this project was the provision of a simple method of integrating a private indoor network into a public 5G mobile network. This 'integration' method needed to be accomplished using a common and well understood interface, in a seamless and simple way that doesn't require significant operator engagement, resources or cost.

The 5G market can only truly thrive if SMEs and enterprises have access to private networks that are easy to integrate with MNOs in a secure and scalable manner. The key elements of technology in the project's architecture tackling this problem is the inclusion of the 5G roaming IPX SEPP N32 Interface, deployed in a containerised solution, which played a vital role in achieving this objective.

4.2. The challenges faced by existing methods

Today, private indoor networks provided by tier 2 vendors are a challenge to integrate, as they require significant resources, network infrastructure investment presenting prohibitively high costs for the MNOs (Mobile Network Operators). As well as the resource and cost implications, there are also concerns over security, operational ownership, training, and uncertainty over regulatory responsibility.

4.3. Business Model development / opportunities

The project aimed to provide a viable, low cost, secure & seamless way to connect private networks to public networks in a cost-effective and secure method that meets regulatory approval. This means that many more SME's can benefit from a 5G installation within their premises, with an estimated 5.6 million SMEs in the UK, that is a substantial business opportunity for everyone.

With private networks estimated to represent a growing market worth circa £5.5bn globally by 2027 with over 100+ private networks already deployed to date. Complimenting a Private Network with MEC capabilities has the potential to improve cost efficiency, accessibility, security, scalability & reliability too.

Through the creation of an integration framework that will foster competition and drive innovation among Tier 2 RAN and oRAN vendors. Enabling a wider range of interoperable vendors and products, which in turn will speed up the diversification of the supply chain, reducing cost and improving functionality options for MNO's, SMEs and Corporates seeking to implement 5G private networks in the UK.

Prof David Owens
5G Drive Project Lead
01.07.2022

5. Customers and other stakeholders.

5.1. Customers and Other Stakeholders

One of the primary focuses of this project was to examine the business case for private networks and identify key stakeholders and vendors essential to the project's success. Throughout the project, we actively engaged with stakeholders through workshops, meetings, and interviews to gather insights and ensure their input was reflected in the project's outcomes. The potential effects of the project on both solution providers and end consumers were carefully considered, and steps were taken to mitigate any negative impacts. Additionally, the involvement of regulators was crucial in anticipating and addressing any regulatory challenges that arose during the project.

5.2. Integration of 3rd Party Networks into MNO Core

The project aimed to deliver a cost-effective, seamless, and secure integration solution framework for corporate clients to implement private 5G network services. This was achieved by utilising existing server room hardware through a containerised approach, ensuring scalability through effective device and user authentication. While the specifics of this integration were out of scope for the High-Level Design (HLD), CISCO managed this aspect, with regular feedback provided by the technical team.

5.3. Neutral Host Integrations

Neutral host companies, which represent or host corporate networks, played a vital role in the commercial success of Private 5G Networks. The project explored business interest levels, potential applications, and opportunities through interviews with key industry representatives, potential customers, regulators, and government bodies. Though this area was also outside the scope of the HLD, CISCO managed it for the project's duration, incorporating insights from the technical team.

5.4. Work with Standards Bodies (3GPP & WBA)

Although outside the scope of the HLD, the technical team actively provided feedback to CISCO to ensure the project aligned with ongoing work in standards bodies such as 3GPP and WBA. This collaboration was vital to maintaining compliance with evolving industry standards, ensuring that our solution remained forward-compatible and robust.

5.5. Business Models

While the development of business models was out of scope for the HLD, the technical team contributed insights to CISCO, who were responsible for this aspect of the project. Ensuring the long-term sustainability of these models is critical, and the project has actively considered more sustainable funding models that could be implemented in the future to support the network's continued success.

6. Network Security considerations

6.1. SEPP/IPX/N32 system

SEPP/IPX/ interface is localised between the MEC and BSCC shall be secured using JWE (JSON Web Encryption) to protect the messages that are sent across the N32, whereas the IPX service providers will use JWS (JSON Web Signatures) to sign any modifications made during transit across the IPX. In order to derive a holistic TVRA process for the platform against known attack vectors and threats (i.e. DDos, Man in the middle attacks, etc.). Further information shall be provided in the corresponding security strategy document from WMG.

6.2. GDPR - Corporate Trialist

Project members were independent controllers of data. The project did not use personal information from end users of the solution demonstrated as part of the trial. During phase 3, when the solution was ready to be demonstrated, we additionally engaged SMEs, and FRANC vendors with private network solutions to trial. Participants in the trial were asked to sign up under the terms of the O2 privacy policy: https://www.o2.co.uk/termsandconditions/privacy-policy.

6.3. O2 Public Network - Carrier Grade security

Both 4G & 5G have 'carrier grade' security built in. 'Carrier grade' refers to a system of both hardware and software components that have been designed from the ground up to provide the best possible security. And it ensures security from the device to the internet, but not end to end. Diverse supply chain for end-to-end platform, utilising open-standard (3GPP compliant) interfaces, with no HRV usage. This section refers to public networks, and not to any test networks that might be built by the project.

6.4. Wavemobile Network Security

The project complied with the requirement to avoid High Risk Vendors (HRVs) for new investment in the 5G infrastructure. We ensured that the current Wavemobile 5G Testbed facilities did not include HRV equipment, in the future diversified supply chain we will need to use an OpenRAN [Ref] that could be used in the 5G DRIVE project once available.

The existing Wavemobile 5G Testbed is securely designed, providing tenant isolation (network slicing, VLANs) and secure P2P links between sites (Oxted, Harwell, Surrey, Warwick & Glasgow). It also offers a secure perimeter through a high spec firewall where proper policies are applied to secure connections and traffic (ingress/egress). The testbed is completely isolated from the operational WM network and access is strictly monitored.

6.5. Internet - Server security

This section covers Application & Server security considerations:

- The security of the applications sits with the developer, to ensure that their services to customers are secure.
- We will ensure Application Servers provide end to end security of the service by implementing; TLS v1.1.2, Strong crypto - AES 128 And SHA-2, & Forward secrecy ECDH.
- Secure perimeter of each facility/virtual stage controlled by carrier grade Firewall

- IPSec VPNs for secure interconnections between sites

6.6. Devices

5G DRIVE will provide core security features to be deployed as appropriate to the stage in the project. The devices will be configured for remote management and will be controlled centrally by the technical team.

6.7. Network and Services Security Strategy

To ensure that the system complies with the Network Security Considerations section and is compatible with the security posture of VMO2 a comprehensive system security modelling and functional testing regime is in place to assess the end to end security of the 5G DRIVE system.

The approach taken to this task is to ensure that both a top down (system security view) and a bottom up (system component view) are incorporated into testing and assurance work. Security research is managed in a second document authored by WMG, and as such will not be repeated in this document.

7. Lesson learned

As we reflect on the project's journey from inception to completion, several key lessons have been identified that can guide future projects and improve processes. These lessons span across project administration, technical implementation, and broader management practices. Below are the significant lessons learned throughout the phases of the project:

- **Setting Up Finance Processes Across Multiple Companies** - One of the challenges encountered was aligning the finance processes across the various partner organisations. Each company has its own internal process for cost and time reporting, which makes coordinating the claims process time-consuming and resource-intensive. This experience highlights the difficulty of implementing a standard process in large, complex organisations.
- **Sign-off Processes Within Large Organisations** - It became apparent that securing sign-offs within large organisations can be a lengthy process, often involving multiple departments. When documents required edits, it sometimes took weeks to complete the approval process. To mitigate this in future projects, initiating sign-off processes as early as the application stage is advisable.
- **Short Timelines for GFA Process** - The time between being awarded funding and getting to a signed Grant Funding Agreement (GFA) was shorter than anticipated. This required significant coordination among multiple departments within each organisation and across partners. The lesson learned is that more time should be allocated for this process in future projects to ensure all aspects are fully understood and agreed upon before milestones and cash flow profiles are finalised.
- **Manual Finance Processes** - The DCMS finance process was found to be very manual, with no direct link between the claims form and the cash flow profile. Aligning these required copying and pasting information, which is prone to human error. A more streamlined and automated process could prevent these issues in future projects.
- **Challenges in Claims Linked to Milestones** - Linking claims to specific milestones proved difficult, as much of the project activity was not directly related to those milestones but still needed to be claimed as part of the overall project goals. Future projects would benefit from a more flexible approach where costs are assigned to work packages, simplifying the management of timesheets and invoices.
- **Security Model for SEPP/N32c Architecture** - Designing and evaluating an effective SEPP security model relied heavily on the security controls between the Home Public Land Mobile Network (HPLMN) and the Visited Public Land Mobile Network (VPLMN). The lesson here is the need for ongoing re-evaluation of the security model against the Confidentiality, Integrity, and Availability (CIA) triad to ensure the network's resilience.
- **Initial Success in Containerising 5G Core Binar**y - The initial attempt at containerising the 5G core binary was less challenging than anticipated, though further work is needed to ensure stability and the ability to deploy in an automated and industrial manner. This success has informed future platform enhancements.
- **Representative Use Cases for Security Modelling** - Effective threat analysis requires representative use cases and misuse cases. Understanding the required system functionality through these examples is crucial for robust security modelling.
- **Challenges in Procurement and Project Timelines** - The procurement of hardware and services impacted project timelines, with delays in the delivery of necessary components requiring workarounds. This experience underscores the importance of including realistic procurement timelines in project planning.
- **Handset Compatibility Limitations** - Finding handsets compatible with specific Public Land Mobile Network (PLMN) codes was difficult, particularly for those supporting the N78 band. This

limitation should be communicated clearly to partners and enterprise customers during the sales process to manage expectations.

- **Importance of Face-to-Face Meetings** - Face-to-face meetings proved to be more productive than virtual meetings, as being in the same room allowed for greater collaboration and faster decision-making. Future projects should ensure that in-person meetings are prioritised where possible, particularly for key decision-making sessions.
- **Comprehensive Threat Modellin**g - The project highlighted the importance of conducting thorough threat modelling and security analysis during the design phase. This approach allows for the early identification of potential vulnerabilities, ensuring that robust security controls are integrated from the beginning.

These lessons provide valuable insights that will be crucial for guiding future projects, improving processes, and ensuring that similar challenges are addressed proactively.

8. Project sustainability

This document has described the 4 phases of our project, covering the design, testing, demonstrations, and deployment milestones that took place from January 2023 to July 2024. The document now serves as the reference design for the weekly Technical Design Group meetings, which began in April 2022, guiding the project's iterative process and solution testing as we progressed towards our third planned demonstration in June 2023 and the final report.

A key achievement of this project has been the successful deployment of a network across 31 remote and rural locations throughout the UK. This network, which is accessible to customers from all major mobile networks, has delivered crucial connectivity to communities that were previously underserved and often completely without coverage.

Wavemobile is committed to maintaining this network for as long as possible. To ensure the network's long-term sustainability, it is recommended that Wavemobile seek support from the governments of England, Scotland, and Wales. Engaging with these governmental bodies could be crucial for securing the necessary backing to extend the life of the network and continue its positive impact. Additionally, exploring more sustainable funding models will be vital for providing ongoing financial support for both the maintenance and potential expansion of this network.

By focusing on these sustainability efforts, we aim to preserve the achievements of the project and ensure that the benefits of improved connectivity continue to serve these communities well into the future.

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Annex A - Acronyms

Acronym	Description
5G-PPP	5G Public Private Partnership
5GV	5G VISTA
5GNR	5G New Radio
5GTT	5G Testbeds and Trials
A&R	Artists and repertoire
AR	Augmented Reality
B2B	Business-to-Business
B2C	Business-to-Customer
CMS	Content Management System
DC	Digital Catapult
DCMS	Department for Digital Culture Media and Sports
FNL	Future Networks Lab
HMD	Head Mounted Display
IEM	In-ear Monitoring
IP	Intellectual Property
KPI	Key Performance Indicator
LTE	Long Term Evolution
MANO	Management and Network Orchestration
MEC	Multi-access Edge Computing
MPEG	Moving Pictures Expert Group
P2P	Peer-to-Peer
QoS	Quality of Service
SAND	Server and Network Assisted DASH
SLAs	Service Level Agreements
SME	Small and Medium-sized Enterprise
TCO	Total Cost of Ownership
TO2	Telefonica-O2
PHASE	Step of the project
UI	User Interface

VR	Virtual Reality
XR	Extended Reality
Headend	Video mixing desk, that handles; encoding & multiplexing
MORAN	Multi-Operator Radio Access Network,
MOCN	Multi Operator Core Network
JOTS	Joint Operator Technical Specification
MNO	Mobile Network Operator
RAN	Radio Network Vendor
Carrier Grade Security	Refers to a system, of hardware and software that has component that are extremely reliable, well tested and proven in its capabilities
Tier 1 vendor	A tier 1 vendor is a large and well-known vendor, often enjoying national or international recognition and acceptance
Tier 2 vendor	A tier 2 vendor is a smaller and less well-known provider as compared to a tier 1 vendor. A tier 2 vendor is often also limited in its geographic coverage as well. Consequently, a tier 2 vendor is generally regarded as a secondary source rather than the preferred source.
Customer	in this definition customer, are corporate customer for mobile networks. In other words, person who use a mobile network or mobile networks services from either public or private network
SME	Small to medium enterprise(s),SMEs with having 0-249 employees. https://www.gov.uk/government/statistics/business-population-estimates-2021/business-population-estimates-for-the-uk-and-regions-2021-statistical-release-html
CIA	When talking about network security, the Confidentiality, Integrity, & Availability, **CIA,** triad is one of the most important models which is designed to guide policies for information security within an organisation
Core Network	The mobile Core Network is the central part of the overall mobile network that allows subscribers to make and receive calls and use

	mobile data services. It also manages security, the location & authentication of subscribers, the roaming process, runs the billing processes and the necessary switching tasks. In 5G rather than using bespoke hardware, the core network uses a Software Defined Network, SDN, with Network function Virtualisation, NFV, which is generally known as the Next Generation Core, NGC.
Radio Network	The Mobile Radio Network implements a radio access network technology that connects mobile handsets to the mobile base stations via radio communications, and provides the onward connection to the core network, normally using fibre.
SEPP	Secure Edge Protection Proxy - Ensures end-to-end confidentiality and/or integrity between source and destination network for all 5G interconnect roaming messages. Enabling secure interconnect between 5G networks.
N32 (c & f)	Negotiation interface 32. This interface provides a separate security negotiation interface (N32-c) and an end-to-end encrypted application interface (N32-f).
IPX	Internet Protocol exchange server
end-to-end system	When we refer to an end-to-end system; we mean a network consisting of the following components: Simulated O2 Core Network provided by Quortus and a radio access network including a mobile device. Data web service to device & voice calls, ms to ms and PSTN to ms.