5G new thinking

Final Report

5G new thinking

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Bogons

Borderlands Inclusive Growth Deal

Neutral Wireless

Rural Community Network

zoetis

co-funded by Department for Digital, Culture, Media & Sport

Executive Summary

5G New Thinking (5GNT) has been an ambitious project that has involved 18 consortium partners working with a number of rural communities across the UK to devise different approaches to help solve the rural connectivity challenge. The consortium developed a 5G testbed network that was built in two remote island locations in Orkney, as well as a number of other testbeds and use case trials in areas such as agriculture and healthcare.

The project explored a range of issues and challenges related to the provision of digital connectivity in hard-to-reach rural areas, encompassing technical aspects of building neutral host networks, business models for community-owned and operated networks, spectrum access, mast site access and planning consent, etc.

A key output has been an on-line Rural Connectivity Toolkit[1] that enables remote communities to learn more about the option of 'self-provisioning' for their mobile and wireless connectivity needs. This reflects many of our findings and lessons learnt, and it serves as a practical guide for rural and poorly-connected communities who are considering building and operating their own next-generation communications networks. It covers a wide range of key topics encompassing business planning, building the network, and subsequently operating the network and running the business.

Enabling digital connectivity in rural areas is challenging – if this were not the case, the mainstream national network operators would already be providing service in such areas. For example, suitable locations for mast sites are often difficult to access and it can be difficult to get equipment to them; cable runs (for optical fibre, electrical power, etc.) can be long and expensive to install; customers are sparsely populated, which makes establishing a business case more difficult. But these hurdles are surmountable, and there is much that communities themselves - with the right information and expert support - can do to enable digital connectivity in their areas.

Each community is different though, and there is no 'one size fits all' solution. Nevertheless, the 5GNT Toolkit provides information and guidance on the key issues and decisions that need to be considered and addressed, and while this does not necessarily guarantee that a commercially viable and sustainable network can be built and operated in every instance, it allows interested individuals to explore what it would take to build connectivity in their communities, and to make an assessment as to whether or not this could viably be done in their particular case.

Creating a financially viable and sustainable business is the key overarching challenge that will face any group of individuals seeking to address a lack of digital connectivity in a particular community. Key specific challenges include, for example:

- **Community Resources and Enthusiasm/Commitment**
  A key feature of projects where communities have developed their own connectivity networks is the presence of a group of committed people who drive the project forward. In some communities, it may be relevant and appropriate to use existing community groups or structures as a starting point. These may be

[1] https://toolkit.5gnewthinking.org

groups that are already formally constituted and have a board of directors from the community.

- **Business Structure and Organization**
  As your project develops, you will probably need to form an incorporated entity, such as a Community Interest Company or Community Benefit Society, which has a board of directors offering a good mix of relevant skills and experience. Ultimately, you are going to be running a business regardless of how you set up your community enterprise and how you resource it. And the usual rules of business apply, including the need to be commercially viable.
- **Business Models and Product/Service Offerings**
  Every community is different, and so, too, are its connectivity needs. When developing an appropriate solution for your community's connectivity needs, you will need to think about the features that are unique to your community. Population density, topography, existing connectivity arrangements and network resources, and socio-economic factors will all play a role in determining the approach and business model that is best suited to your community. The 5G New Thinking Toolkit has tools that can help you to explore different cost/revenue models and assess their viability.
- **Backhaul**
  Good 5G coverage (or even 4G coverage for that matter) requires adequate backhaul infrastructure. In many rural settings, this will require backhaul to be provisioned specially for the network, but this can be a lengthy process and the annual costs of backhaul and Internet connectivity can be high and need to be factored in to the business models.
- **Access to Radio Spectrum**
  Ofcom's Local Access Licence (LAL) and Shared Access Licence (SAL) mechanisms represent a significant step forward in improving access to spectrum and improving overall utilization of spectrum. However, our experience suggests that more work is required to make such mechanisms work effectively as originally intended. We found that licences in LAL spectrum were difficult and time consuming to obtain. Obtaining licences in SAL spectrum was slightly easier, but even here, the 'first come, first served' basis on which these are allocated is potentially limiting, particularly if the licence-holder doesn't need to use the spectrum continuously. An automated, DSA-like approach could potentially help to allow this spectrum to be genuinely shared among more than one user, and we recommend that this be given consideration. In some cases, it can make good sense to use point-to-point microwave links for backhaul connectivity to mast sites. However, these generally require their own spectrum licences, and the annual cost of these needs to be factored in to any business plan. One potential approach to alleviating this might be for Ofcom to consider the creation of special, reduced-rate tariffs for qualifying rural community organizations.
- **Neutral Hosting**
  In principle, Neutral Hosting has the potential to be an effective way of connecting a remote rural community network to one or more national MNO networks. While research has indicated that MNOs are keen to roll out 5G in rural locations, there

is some resistance towards working with rural neutral hosting providers, and commercial terms and conditions would need to be agreed. Whether MNOs would be willing to enter into such commercial arrangements with multiple local community organizations remains to be seen. Our experience would suggest that it seems unlikely, and future work is needed to work through the issues and come up with acceptable solutions. Alternative approaches, such as the use of Dual-SIM handsets or local not-spot roaming, could be considered instead, but they have their own sets of pros and cons associated with them.

- **Handset Carrier Customisation**
  Operators of small or private networks often do not have the scale required to qualify for OEM carrier locking or OEM TAD configurations. Implications of this include:
  - When a private network SIM card is inserted to an unlocked phone, the phone may attach to 2G and 3G cells only. APN settings must be manually configured to enable a 4G or 5G attach.
  - When connecting an unlocked phone to a private 4G/5G network, there is a significant probability that the phone will not support 4G VoLTE or VoWi-Fi calling.
  - There have been reports of advertised '5G NSA capable' unlocked phones refusing to attach to 5G NR cells for certain operators, even though the same phone will happily attach to similar cells from another operator following a SIM swap and factory reset.
  - As with the 5G NSA point above, it appears that some device manufacturers are shipping 'unlocked' 5G phones that do not support 5G SA without TAD. This is a cause for concern, as it will act as a barrier to the rollout of private 5G SA networks.

  The key concern here is that small operators and operators of private networks will face issues with the customisation of phones when deploying 4G/5G networks, and this will have an impact on the business models and viability of private networks which seek to make use of consumer mobile handsets. Resolving this may require regulatory intervention along similar lines to the banning of the sale of carrier-locked phones, which Ofcom introduced for the UK in December 2021.

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In conclusion, the 5G New Thinking project has explored a considerable number of factors related to rural connectivity and the use of 5G to alleviate the challenges. Challenges undoubtedly still remain, and some of these will require the involvement of government and key industry players working together to implement suitable solutions. Nevertheless, there is much that communities themselves can do, and our Rural Connectivity Toolkit provides communities with key ingredients and guidance for planning, designing, financing, building, and operating the infrastructure required to address their connectivity needs.

Contents

List of Acronyms

APN	Access Point Name
ARFCN	Absolute Radio Frequency Channel Number
BBU	Baseband Unit
CDMA	Code Division Multiple Access
CPE	Customer Premises Equipment
CUPS	Control and User Plane Separation
DCMS	Department for Digital, Culture, Media, and Sport
DSA	Dynamic Spectrum Access
EARFCN	E-UTRA Absolute Radio Frequency Channel Number
eMBB	Enhanced Mobile Broadband
eNB	Enhanced Node B – essentially, a 4G basestation
ESN	Emergency Services Network
FTTC	Fibre To The Cabinet
FTTH	Fibre To The Home
FTTP	Fibre To The Premise
FWA	Fixed Wireless Access
gNB	5G basestation
GSM	Global System for Mobile communications (2G)
HRV	High Risk Vendor
ISP	Internet Service Provider
KPI	Key Performance Indicator
LAL	Local Access Licence
LTE	Long-Term Evolution
MEC	Mobile Edge Computing
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
NHO	Neutral Host Operator
NR-ARFCN	New Radio (for 5G) ARFCN
NRFCN	NR
NSA	Non-Standalone

PLMN	Public Land Mobile Network
RAN	Radio Access Network
RRH	Remote Radio Head
SA	Standalone
SAL	Shared Access Licence
SDR	Software Defined Radio
SIM	Subscriber Identity Module
SLA	Service Level Agreement
SRN	Shared Rural Network
TAD	Technical Adaptation of Devices
UE	User Equipment (e.g. a mobile handset)
VNO	Virtual Network Operator
VoLTE	Voice over LTE
VoNR	Voice over NR
VoWi-Fi	Voice over Wi-Fi
WISP	Wireless Internet Service Provider

1 Introduction

5G New Thinking (5GNT) has been an ambitious project that has involved 18 consortium partners working with a number of rural communities across the UK to devise different approaches to help solve the rural connectivity challenge. The project, which ran from May 2020 to March 2022, was supported by DCMS's 5G Testbeds & Trials Programme.

This report describes the key activities and outputs of the project. It covers the 5G testbed network that was built in two remote island locations in Orkney, as well as a number of other use case trials and testbeds in areas such as agriculture and healthcare. It also covers work carried out in the area of business models, operating models, and funding and financing.

A key output of the project has been an on-line Rural Connectivity Toolkit[2] that enables rural and remote communities to learn more about the option of 'self-provisioning' for their mobile and wireless connectivity needs. The Toolkit is essentially the culmination of two years' work by private, public, and academic consortium members, and it builds upon the learnings and insights from the 5G RuralFirst project that was undertaken in 2018-2019.

[2] https://toolkit.5gnewthinking.org

2 Orkney Testbed

In order to support and inform the development of the 5G New Thinking Toolkit, a testbed network was designed and implemented in Orkney. This was done via collaboration and cooperation with the Scotland 5G Centre's 'Wave 1' Rural project[3], which provided funding and support for the radio equipment and 5G core used in the 5G New Thinking Orkney testbed.

The Orkney testbed network was used to run use case trials to support the testing and evaluation of various aspects of 5G technologies and business models. The results and learnings fed directly into the toolkit design and development activities, helping to guide and inform the toolkit formation.

2.1 Network Overview

The 5GNT Orkney testbed provides coverage across two 'clusters', shown in Figure 2.1. Cluster 1 encompasses two remote islands in the north of Orkney; Cluster 2 encompasses three remote islands in the south of Orkney. Both clusters have very poor fixed broadband connectivity and poor cellular data coverage from UK MNOs.

The overall aim was to create a network that has a good level of high-quality LTE macro coverage 'everywhere', with smaller areas of 5G NSA and 5G SA coverage delivered via 5G NR radios. This, in turn, enables 4G & 5G NSA connectivity to mobile phones (as 5G SA is not currently supported by most handsets) in premises, roads, and countryside throughout the clusters, and 4G and 5G FWA to premises as well.

2.1.1 Cluster 1 – Westray & Papa Westray

Cluster 1 provides coverage in two islands which lie in the north-west of Orkney:

- Westray, with an estimated population of 620 people living in 248 premises;
- Papa Westray, with an estimated population of 90 people living in 72 premises.

Papa Westray is a small community which has limited services. It is served by a small passenger vessel which is there to provide community access (including doctor/NHS nurses, school pupil transport) daily to and from the island. This service operates from Westray and can be a demand led. The service does not run in certain weather conditions, which are often too poor for a sailing.

Flights to/from these islands are up to three times per day, using a shared aeroplane 'shuttle' service with North Ronaldsay. These flights, which are operated from the town of Kirkwall (on the Orkney mainland) are considered a lifeline service to the islands of Papa Westray and Westray. The service is often fully booked, and advanced planning is required in order to book a seat. These flights can carry only 8 passengers – 9 if the captain allows the co-pilot seat to be used, but this is done only in exceptional circumstances.

[3] See: https://scotland5gcentre.org/5g-projects/s5gc-projects/projects-5g-scotland-rural-testbed/

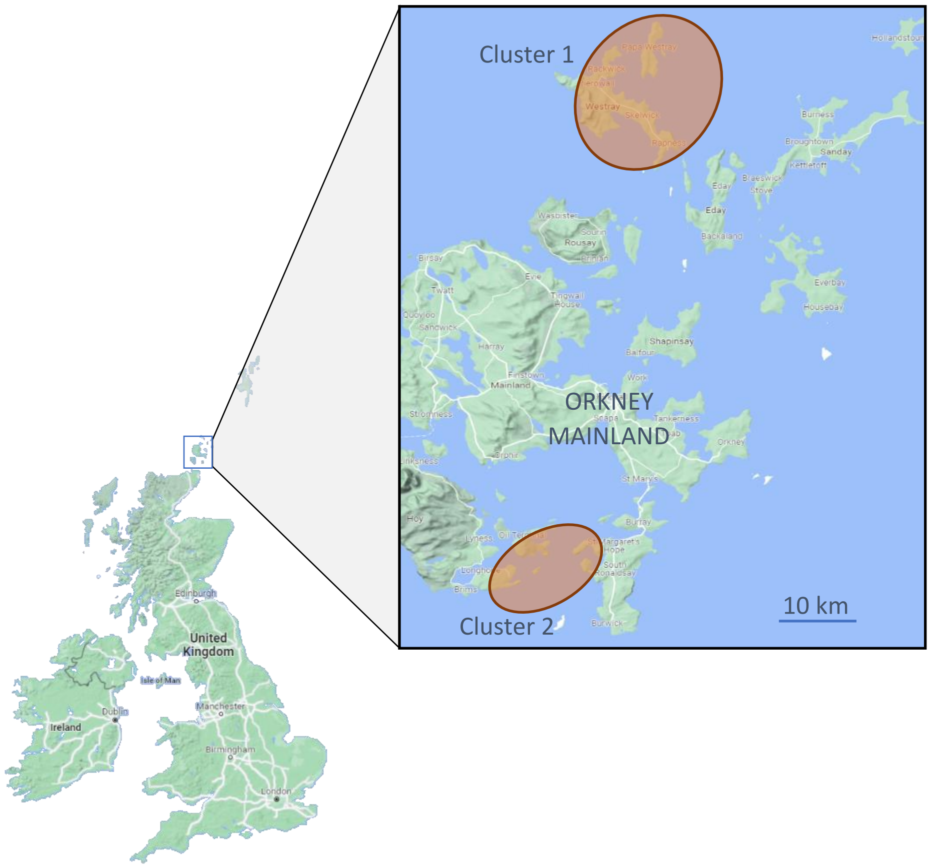


Figure 2.1: Map showing locations of testbed coverage areas.

One supply vessel per week is scheduled to provide essential goods and services via the Orkney Ferries passenger vessels. This provides craned lift on/lift off facilities to bring farming equipment, essential food supplies and other bulky goods on/off the island. However, this service is regularly cancelled due to bad weather, meaning that in the winter months it can often take 2-3 weeks to reach the islands. Communications services are critical for such a community in these circumstances.

Figure 2.2 shows the site locations for Cluster 1. The mast site at Kirkbrae is the 'hub' site for the cluster. It is connected to a nearby fibre 'Point of Presence' (PoP) which connects the entire cluster to the UK mainland and ultimately to the Internet. The other three sites at Woo, Clestrain, and the Ambulance Station are connected to the Kirkbrae hub site via microwave radio links, and all four sites provide 4G/5G coverage in their respective vicinities. (Note that the site at Clestrain on Papa Westray is connected to Kirkbrae via the Ambulance Station site – i.e. the Ambulance Station site acts as a 'local hub' for Papa Westray.)

Figure 2.2: Site locations for Cluster 1.

2.1.2 Cluster 2 – Hoy and Flotta

Cluster 2 provides coverage in three islands which lie in the south-west of Orkney:

- South Walls, with an estimated population of 230 people living in 151 premises;
- Hoy, with an estimated population of 190 people living in 128 premises;
- Flotta, with an estimated population of 90 people living in 75 premises.

Hoy, measuring 143 square kilometres (55 sq mi), is the largest island after the Orkney mainland. A natural causeway, the Ayre, links to the much smaller island of South Walls; these two islands are treated as one entity. Hoy is probably most famous though for the stack of the Rackwick coast; the Old Man of Hoy, a sea stack formed from Old Red Sandstone, it is one of the tallest stacks in the United Kingdom at a height of 449 feet (137 m). The Old Man is popular with climbers, and was first climbed in 1966. The dramatic coastline of Hoy can be seen by visitors travelling to Orkney by ferry from the Scottish mainland. It has some of the highest sea cliffs in the UK at St John's Head, which reach 350 metres.

The northern part of Hoy is an RSPB reserve due to its importance for birdlife, particularly great skuas and red-throated divers. Hoy played a vital role during both World Wars and the rich heritage legacy continues to leave a lasting impression on the island today. It is one of the most visited islands by tourists.

Flotta is a small island lying adjacent to Hoy. The island is known for its large oil terminal with a workforce commuting from the Orkney mainland to work at the terminal. The resident population of working age relies on agriculture as its main source of income.

Figure 2.3 shows the site locations for Cluster 2. In this case, the hub site is the Ayre of Cara, which is connected to the SHEFA-2 under-sea fibre cable[4] which provides a connection to the UK mainland and onwards to the Internet.

The sites providing 4G/5G coverage are North Walls and South Walls. The other sites are relay sites which connect North Walls and South Walls to the Ayre of Cara hub. (Note that all sites except Manse Bay use microwave links, shown as blue lines, for their backhaul connectivity; Manse Bay uses a specially-laid fibre link, shown in orange.)

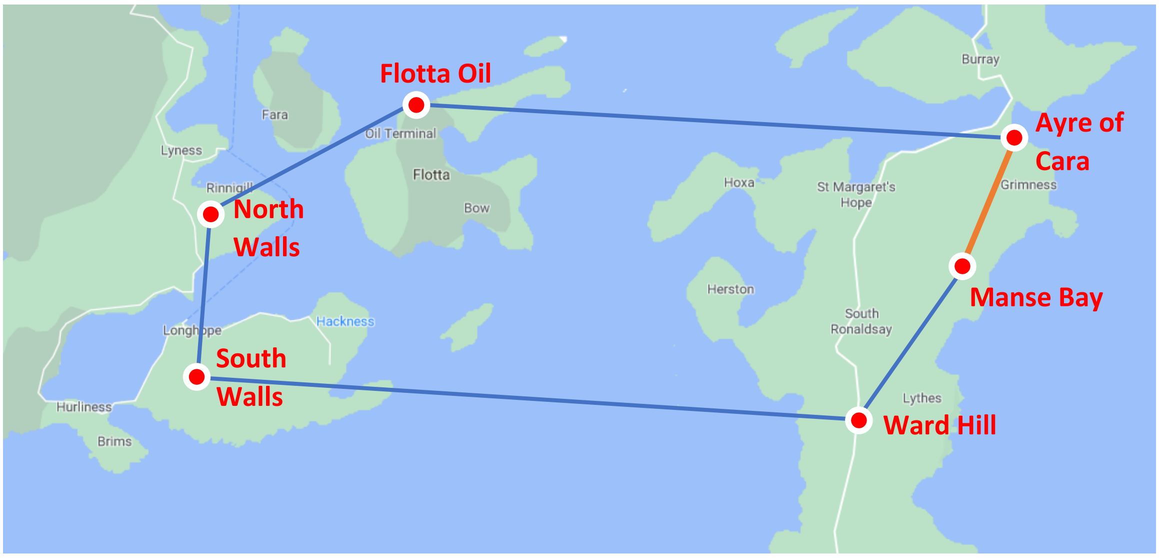


Figure 2.3: Site locations for Cluster 2.

2.2 Network Design & Implementation

The design and implementation activities were carried out in two separate, albeit related, stages. The **design** stage involved making design decisions related to all aspects of the network, encompassing overall requirements and expectations, the radio access network and spectrum licensing, mast site locations and construction, the backhaul network (microwave and fibre), electrical power supply, comms rooms/cabinets, etc. The **implementation** stage involved building and constructing the network according to the design.

2.2.1 Design

The design stage involved decisions being made regarding numerous aspects of the network, as illustrated in Figure 2.4. It was essentially iterative in nature, taking the broad requirements of the network and the desired coverage as a starting point.

The first step involved identifying potential mast site locations, based mainly on some preliminary studies of the terrain coupled with local knowledge of the area and landowners.

The next step involved running RF coverage simulations from each of these potential sites and essentially working out the best combination of sites that would be likely to achieve the desired coverage most efficiently. This involved various factors having to be repeatedly

[4] See: https://www.shefa.fo/expert/

considered in an iterative manner. For example, what radio frequency bands would be used and how easy would it be to acquire spectrum licences? How easy would it be to provide backhaul connectivity to the site? Where would the electrical power come from? How easy would it be to access the site and transport equipment to it? Is the landowner known, and if so, is he/she likely to be amenable to discussions and negotiations on allowing the site to be used for our purpose? Is planning consent required, and if so, how likely is it that such consent will be granted? The outcome of this stage was a provisional list of suitable mast sites, which was used as the basis for carrying out the high-level network design.

The high-level network design involved the specification of decisions such as radio frequency bands and transmit power levels for each basestation, the backhaul approach for each basestation site (e.g. fibre, microwave), data throughput capacities, mast heights, the approach to security, etc. Once again, this was an iterative process involving local knowledge and discussions with landowners.

It must be borne in mind that at any point in this entire process, it could transpire that a particular mast site location is no longer viable. Landowners can change their minds; planning consent may turn out to be problematic; there may be technical issues. In such situations, it becomes necessary to go back to the beginning and start again, with an alternative site in mind.

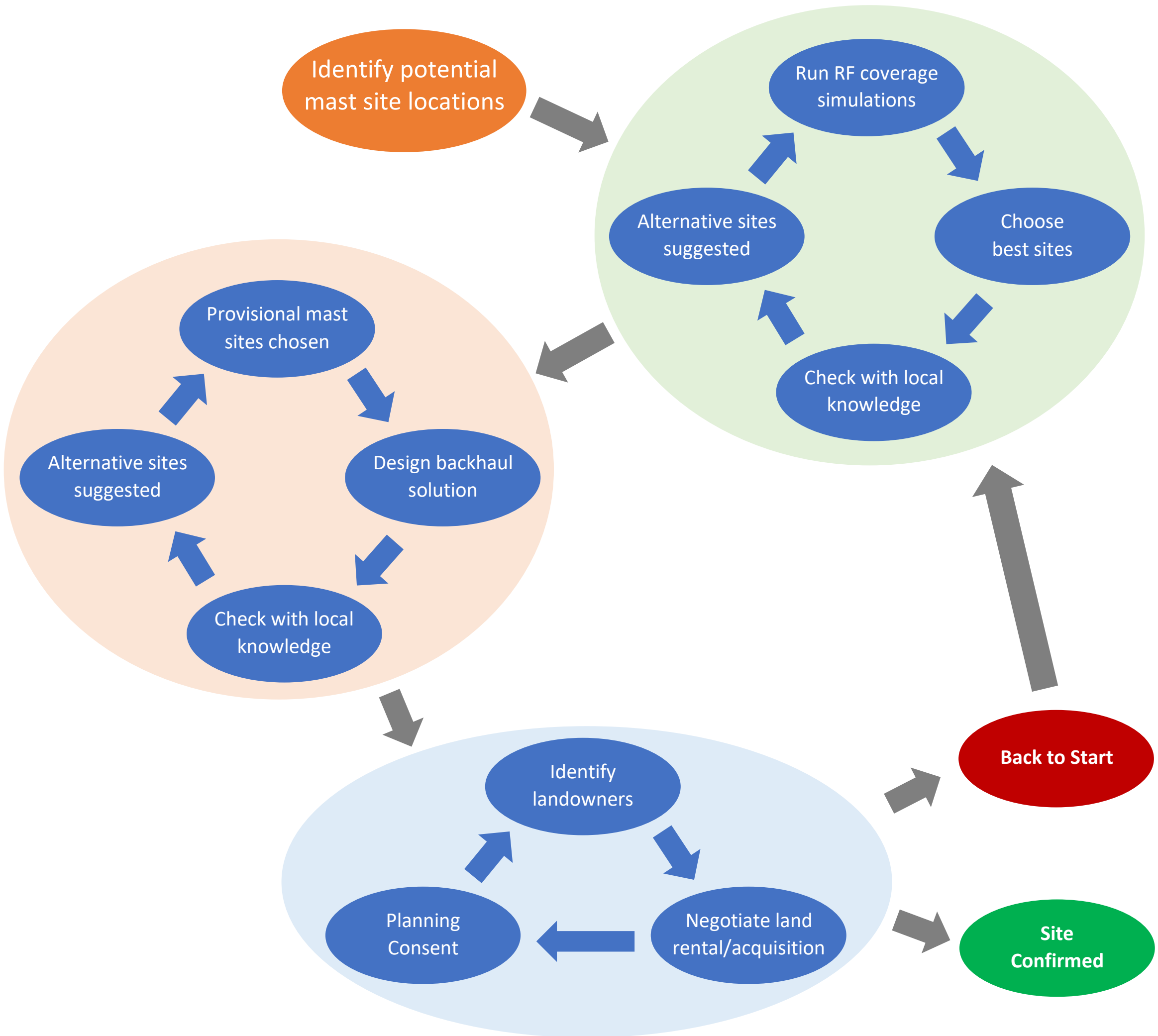


Figure 2.4: Illustrating the iterative nature of the network design flow.

Once a high-level design was arrived at, a low-level (detailed) design was created. This expressed the various design choices and design parameters in detail, including network configuration and IP addressing parameters, etc. In addition, a Bill of Materials (BOM) was created, along with an implementation plan.

2.2.2 Implementation

The implementation of the network involved various activities: preparing the mast sites; procuring masts, radio equipment, cabinets, backhaul, electrical power, etc.; installing and configuring the various network elements – switches, routers, firewalls, 5G cores, etc.

The networking equipment had to be procured, tested, assembled, and configured prior to installation. Some of this was done on-site, but for the most part, as far as possible, it was done in the lab. Figure 2.5 shows some of the lab testing and assembly of kit being prepared for shipping to Orkney.

Figure 2.5: Equipment being assembled and tested in the lab.

As an illustrative example of site build activities, we'll consider the build and commissioning of the site at Kirkbrae on Westray – the hub site for Cluster 1.

Kirkbrae Hub Site

The Kirkbrae site, shown in Figure 2.6, is part of a field owned by a local farmer. It was not used much by the farmer but as it was only 30m from a fibre PoP at the local telephone exchange, it was a good site for the project. It also had good visibility of the other sites in Cluster 1, which allowed microwave backhaul links to be used for connecting to those sites.

Figure 2.6: Kirkbrae hub site.

Site Acquisition

Acquiring the site required some discussion and negotiation. As is often the case, local landowners are usually keen to support the community's endeavours but they also want to ensure that they derive 'reasonable' value from their land. The right balance has to be found, and in this case, the negotiations ended up converging on an agreement to pay an annual site rental fee and providing free Internet access for the farmer.

Planning Consent

Planning consent had to be applied for, and planning applications can often take several months to process. In the case of our site at Kirkbrae, an objection was raised and this had to be addressed and dealt with, which resulted in delay. In the end, planning consent was eventually granted 5 months after the application was submitted.

Site Preparation

Site preparation for the Kirkbrae site was relatively straightforward and was carried out by local contractors. First the site was craped and cleared of unwanted rubble. The site was then excavated and the foundations were laid for the tower and comms room.

Figure 2.7: Concrete plinth for comms cabinet, with power and communications ducting laid out prior to installation.

Electrical Power

Getting electrical power to the site required the electricity supplier (SSE) to install a new transformer and associated switchgear, and a 40m dig was required in order to route the power cable to the mast location.

Fibre Backhaul

The mast site is close to the local telephone exchange, which provides the 'Point of Presence' (PoP) for the Cluster 1 RAN. A 30m fibre run was required, from the mast site to the neighbouring telephone exchange – this work was carried out by a local contractor and was funded via collaboration with the Scotland 5G Centre 5G Rural project.

Figure 2.8: Fibre run for Kirkbrae hub site.

Mast and Comms Room Installation

Once the site had been prepared and foundations had been laid, the comms room and mast were installed. Arrangements had to be made for lifting machinery to be available on site for this, and for island locations such as this one, reliance on ferries is a key factor. Figure 2.9 shows some photos of the installation operations in progress.

Figure 2.9: Installation of comms room and mast at Kirkbrae hub site.

Radio Equipment Installation

Figure 2.10 shows the 5G radio equipment attached to the mast while it was still on the ground, prior to it being installed. (This isn't always viable, but when it is, it can ease the overall installation operation considerably.)

Figure 2.10: Radio equipment installed on mast.

Figure 2.11 shows the microwave backhaul links to Woo and Papa Westray being installed. (Note: Tower-climbing activities are subject to various health and safety rules and must be carried out by suitably certified personnel.)

Figure 2.11: Radio equipment being fitted to towers.

Other Sites

Other sites were built in a similar manner, although it must be emphasized that no two sites are ever exactly the same! In some cases, the radio equipment can be attached to a pole mounted on the side of a building rather than a standalone mast, for example, and the details of a particular site will depend on the radio and backhaul links being installed. A particular challenge for sites on remote islands is getting the necessary heavy machinery to the site. This requires space to be booked on ferries (see Figure 2.12), and it relies on the ferries actually running and not being cancelled due to weather!

Some islands (e.g. Papa Westray) do not have docking facilities for roll-on-roll-off vehicle ferries – all goods need to be loaded and unloaded by crane. Our installations on Papa Westray therefore relied on machinery that was already on the island, which tended to be farming machinery rather than mobile cranes and the like.

Site build costs vary from site to site and are highly dependent on the geographical features and specific functionality being implemented. However, a rough indication of typical costs can be given as approximately £120k for a hub site, £75k for a relay site, and £40k for an edge site. Ongoing operational costs such as electricity and land rent also need to be taken into account as well of course, and these, too, vary from site to site and may also depend on favourable negotiations at a local level.

Figure 2.12: Crane on ferry for North Walls installation.

Network Cores

The Orkney testbed network requires 4G, 5G NSA, and 5G SA cores. These are located on cloud-based servers on the UK mainland, and the basestation radios in Orkney connect to the cores via the backhaul connectivity provided by the PoP at Westray Kirkbrae, in the case of Cluster 1, and the Ayre of Cara, in the case of Cluster 2.

Network Monitoring

In order to monitor network status and performance, a network monitoring and operations centre (NOC) was established, accessible via the Internet for authorized users. This is illustrated in Figure 2.13.

Consumer Premises Equipment (CPE)

The Orkney testbed was used for Fixed Wireless Access trials, with residents in the coverage area recruited as trialists.

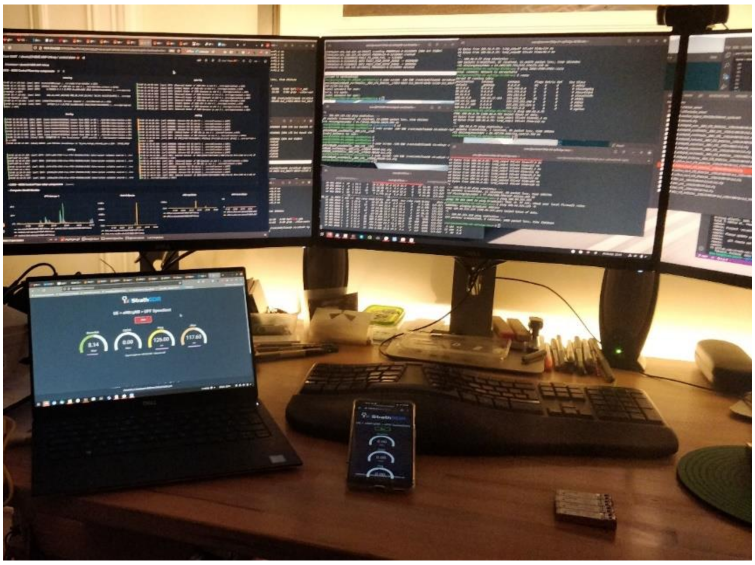


Figure 2.13: Network Monitoring.

2.3 Security Considerations

One of the technical components being trialled on the Orkney testbed was an implementation of a zero-trust mobile network. This is a 'new thinking' approach, as normally mobile operators trust their RAN, core, and all backhaul. Due to the efficient network design and use of cloud servers that were accessed over the public internet, it was not possible to trust everything in our testbed network. Therefore, all connections in the 4G/ 5G NSA/ 5G SA Radio Access Network (RAN) and core network (featuring a centralised control plane and multiple edge-deployed user planes) were End-to-End Encrypted (E2EE) using SD-WAN/ mesh VPN software. There was a slight encryption overhead associated with this (encrypt time, packet overhead, decrypt time), but we did not record any performance issues.

All remote management of the network was carried out using certificate based SSH, with a cloud bastion server, running over another VPN solution. Therefore, all remote access was completed using a layered encryption approach for Security in Depth (SID).

Each server in the RAN + core networks featured a firewall, which was completely closed on inbound physical ports. Ports that were open (for S1-MME, S1-U, X2, N2, N3, Xn, Sxa, N4 and N4u mobile interfaces) were associated with virtual port interfaces used by the E2EE SD-WAN/ mesh VPN software, and the VPN used for SSH remote access.

It should be noted that the VPN software used in both instances was ‘next gen’, and does not adopt the industry standard “just use IPSeC” approach. Newer, more efficient algorithms are used in this software, which also enables the SD-WAN and mesh VPN features. And while these approaches have not (yet) gone through US Govt NIST or UK Govt NCSC accreditation, this is something that may happen in the future. We should note, however, that the approaches we have adopted use encryption algorithms that are acceptable by both NIST and NCSC. While we didn't use IPsec as the protocol, the cryptographic protection of the data carried will have been equivalent.

There is a publicly accessible web interface for the Network Operations Centre (NOC). Partners logging in through this method have query/display read only access to the data, and are unable to modify any of the queries or the dashboard layouts. The admin account can only be accessed through another VPN solution. All servers feeding data to the NOC use a VPN to transmit the data. The NOC is running over HTTPS, so is E2EE from the server to the user’s computer. The back-end time series database of the NOC is not publicly exposed. The web user interface runs through a proxy server.

In summary, the Orkney testbed network has been based on an innovative, cost-effective approach that makes use of public network connectivity, which required us to adopt a ‘zero trust’ philosophy that involved ‘encryption everywhere’. Further testing is no doubt required, but our observations thus far indicate that the approach appears to be bearing up well.

3 Use Case Trials

Viable new commercial solutions will need to be based on more than simply providing consumer mobile services. Our experience from 5G RuralFirst shows that there is a wide range of business situations in which connectivity, and 5G in particular, can deliver benefits and new service revenue for network operators, as witnessed by the agriculture, salmon farming, and renewable energy use cases that were explored in that project. In most of these cases, a viable business case cannot be based on consumer demand alone, and a more integrated approach is needed. 5G New Thinking has therefore considered new applications and market opportunities for 5G, with a view to identifying ways of achieving economies of scale through addressing multiple markets and applications in each rural location area.

3.1 Agri-Tech

This section provides the results of three use case trials undertaken by Agri-Epi Centre. Each use case was demonstrated within the agri sector and took advantage of agri-tech technologies in order to demonstrate the usability of 5G.

3.1.1 Overview of the Use Case Trials

Use Case 1: 5G to improve beef profitability

This use case trial took place in a rural Estate in Southern Scotland. The Estate covers some 220,000 hectares with 85,000 hectares being used for beef farming.

The trial was focused on creating a more efficient slaughter selection process. Farmers are paid on a grading system for their beef carcasses (EUROP Grid System); there are 20 different grades within the grid and each grade has a specific spec and price attached to it. An efficient farmer will aim to achieve the premium grades to get a greater return on investment. There are huge penalties for not hitting grade specs. These can be up to 30-40p/kg on an average 360-380kg carcass (360kg spec being the premium) – the financial loss can be considerable. The idea is to ensure that the animal is a prime weight so that the carcass weight will hit the premium specs on the EUROP Grid. By actively monitoring weight gain and conformation, the process will be simplified and will become more efficient.

The technology set-up is illustrated in Figure 3.1. It involves a camera which generates 3D points clouds, and these are put through machine learning and segmentation algorithms to determine weight and grade. The camera took images that were sent via 5G, and designated algorithms helped to determine the weight and, in turn, the optimal slaughter selection. The algorithms converted the images into a conformation statement that allowed the farmer to decide when the animal is at its optimum stage for slaughter.

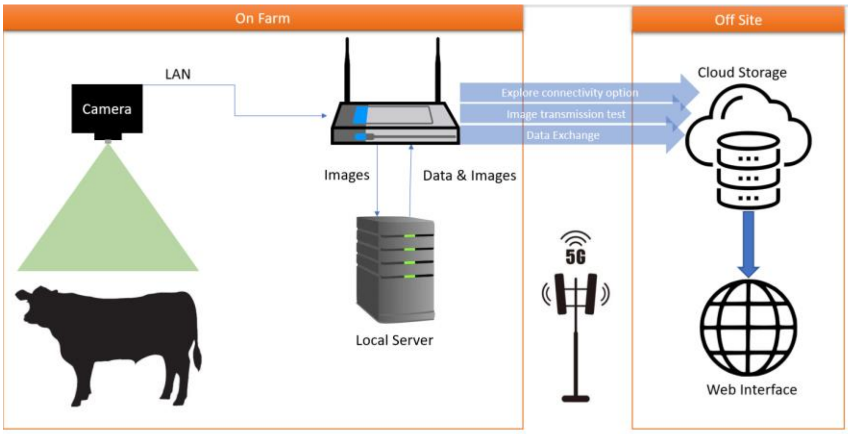


Figure 3.1: High-level illustration of Use Case 1: 5G to improve beef profitability.

Use Case 2: 5G By Air

This use case trial took place in the Agri-EPI Centre's South West Dairy Development Centre, Beard Hill, Shepton Mallet, using the rich fertile fields within the confines of the farm. The farm was part of 5G Rural First, where trials on 5G data collection were first held. This differs from that project but takes learnings from it. By overcoming connectivity issues, it was hoped that the data collected would be more than just biomass and feed value. From the superior data collected it is possible to measure not only how much biomass and feed value there is but also its feed value. More accurate, real-time data can ensure that grazing is supplemented when it needs to be.

A drone system that houses a multi-spectral camera along with a 5G device, as shown in Figure 3.2, was used to make measurements from the air and transmit in-flight data in real-time via 5G to ground-based servers.

Figure 3.2: A drone with multispectral camera scans the grazing to measure biomass and feed values. Data is transmitted in real time by 5G.

Use Case 3: 5G Transferrable learnings from Smartbow Technology

This use case trial also took place at the Agri-EPI Centre's South West Dairy Development Centre (SWDDC), Beard Hill, Shepton Mallet. The Centre is a state-of-the-art dairy centre that combines leading edge building design with precision grazing. The ambition is to exploit sensors, automation, and robotics to optimise dairy cow welfare in order to improve productivity through the production of a consistently good quality product, leading to the maximising of profits whilst reducing environmental impact. The intention, in the future, is to operate a circular farming system and establish SWDDC as a leading exemplar of circular farming.

Zoetis used their existing SMARTBOW technology to aid with the delivery of this trial. SMARTBOW is an advanced dairy cow monitoring system which allows the management of individual cows in order to achieve their full potential, providing fertility and health insights, and enabling the herdsperson to take timely and appropriate action.

A cow's ear shows a very distinctive and recurring movement pattern while ruminating. By detecting these characteristic movements, SMARTBOW can analyse the rumination activity and precisely deliver insights regarding a cow's health status. It allows:

- The identification of health issues and diseases earlier
- Enhancement of intervention success
- Optimisation of herd management and animal well-being
- Reduction in illness-related losses and culling costs

The technology uses an ear tag which transmits data to wall-mounted receivers (there are several around the indoor unit) which allow full coverage wherever the cows go within the confines of the indoor facility. Data is passed back and forth between the receivers and the server/PC on the farm via ethernet. The system is illustrated in Figure 3.3.

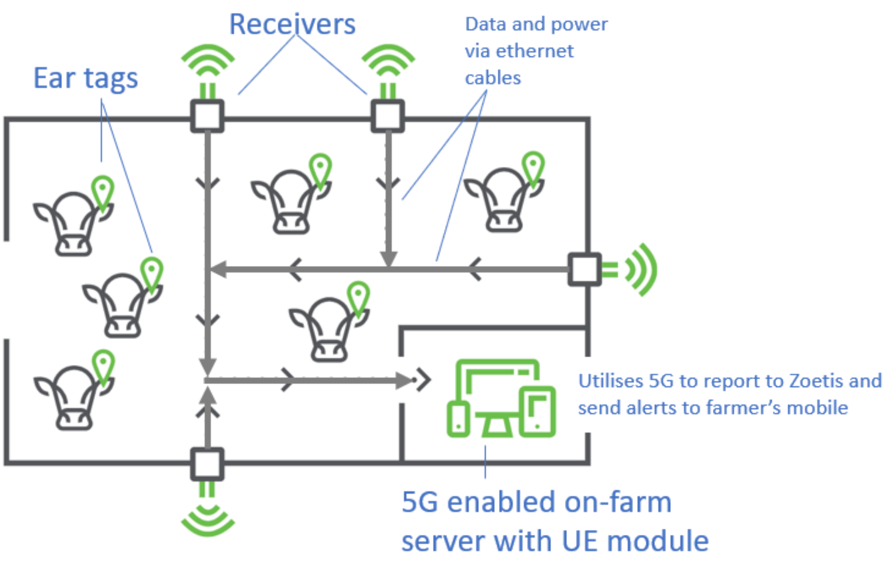


Figure 3.3: Illustration of SMARTBOW system, in which ear tags send data to wall-mounted receivers.

A stable internet connection on customer farms for the server to connect to is critical for operation of the SMARTBOW system. A central application in a cloud environment monitors the SMARTBOW system on the farm by connecting every two hours and querying certain system parameters. The central application also pushes updates to the on-farm servers. Data from the server is exported to the cloud for research and consulting purposes. Data is also backed up in the cloud from the on-farm server every night, which ensures there is enough space on the server to continue to receive and process data from the receivers.

While SWDDC has fibre broadband direct to the building with 1GB download speed, terminating in the herdsman's office, this is highly unusual – many farms are poorly served by any form of broadband connection, which is why 5G connectivity offers such good potential for enhanced data capacity on most farms.

On farms with a poor connection, the status of the farm cannot be determined, and remote technical support, including system monitoring, and cannot proactively respond to any kind of issue. Software updates fail and must be restarted again and again. The SMARTBOW farm server cannot back up data, and this can lead to data loss and inaccurate alerts to farmers as well as a lack of research data. On such farms, it is not possible to provide the optimal SMARTBOW service. 5G connectivity has the potential to overcome these issues, improve customer experience, increase efficiency in customer support, and expand the pool of potential customers.

3.1.2 Implementing the Trials

There were similarities in how the three trials were implemented. Figure 3.4 shows photographs of the actual installation at the farm in Southern Scotland for Use Case 1 (5G to improve beef profitability). The costs for purchasing, installing, and configuring the mast came to approximately £45k in total – this includes the costs of the mast and accessories, civil works for installing the mast, and basestation radio components.

Figure 3.4: Deployed system for Use Case 1.

Figure 3.5 shows the 5G-enabled multi-spectral drone system in flight for Use Case Trial 2 (5G by Air).

Figure 3.5: Drone in flight, with 5G link highlighted by the green line.

Use Case Trial 3: 5G Transferrable learnings from Smartbow Technoloy

For Use Case Trial 3 (5G Transferrable learnings from Smartbow Technology), Zoetis adapted the FarmServer to be 5G enabled. This involved connection to an external UE module capable of operating from the 5G signal provided by the same mast/ base station mast for the 5G by Air.

3.1.3 Trial Results

Use Case 1: 5G to improve beef profitability

Images are now being sent back to the EDGE computing server, where they are being analysed using Bayesian MCMC-based data cleaning and interrogation code. Over time, this will provide a system of identifying correct slaughter date. Seven data points will be measured per animal per day for 3 years. Doing this for 25 animals will equate to just over 190,000 carcass images.

Measured benefits include a reduction in carcass payment penalties – typically 7 days over-finished, so a saving in penalties of £20 per animal on average. Factoring in the lower feeding and accommodation costs as well as the reduction in penalties, current estimates put the overall benefits at £38 per animal, which equates to approximately £11,000 per year for a farm of this size.

Use Case Trial 2: 5G by Air

This use case trial was designed specifically to demonstrate that 5G capability can increase the efficiency of agricultural monitoring and can support the continued development and adoption of precision agricultural techniques. In this case, we looked to demonstrate how improved operations could lead to increased profit margins to the farmer as a result of making use of improved UAV capabilities.

Drones are able to cover land quickly and efficiently, but the cost of utilising licensed UAV pilots to operate them over several days means that it becomes prohibitive for many. The idea was to test if images of grasslands and measurements of biomass and feed value could be taken and downloaded whilst the drone was in flight rather than having to land the drone periodically and manually transfer the data. If this could be achieved, it would result in a reduction in the overall number of pilot-days needed.

A reduction of 30% was achieved, and although this fell short of the target that we were aiming for (50%), we believe this was due mainly to the fact that the drone being relatively old and capable of flying for only 9 mins before having to land and have its batteries recharged. A more modern, more capable drone with a longer flight time capability would have yielded better results. Nevertheless, the use case trial demonstrated that 5G-enabled drones can facilitate live streaming of measured data while in flight, resulting in overall reductions in measurement time.

Use Case Trial 3: 5G Transferrable learnings from Smartbow Technology

In order to improve the commercial viability of SMARTBOW, Zoetis sought to assess the potential for 5G to realise three benefits:

SMARTBOW Benefit 1: Capacity to move higher volumes of data faster to a cloud-based environment to build the basis for new analytic capabilities and data integration in the future. The 5G connectivity provided connectivity that, while not as good as that achieved from fibre, was nevertheless far superior to that which was typically available in many rural farms.

SMARTBOW Benefit 2: Stability and reliability of connection to ensure remote support capability and therefore improved farmer confidence in real-time monitoring. 5G connectivity had a network uptime of 99.23%, which compares favourably with the 99.98% that was achieved with the fibre connection.

SMARTBOW Benefit 3: Demonstration that SMARTBOW can operate at full capacity on 5G, leading to market expansion via sales to farms that currently have poor internet access. During the trial period, no system failures were recorded, thus demonstrating that 5G connectivity has the potential to be very reliable.

3.2 Portable Non-Invasive Radio Frequency Sensing for Assistive Living

It is envisaged that 5G will serve several applications and use cases that require split-second decisions, especially in health-care settings. This use case, led by the University of Glasgow, developed a portable non-invasive Radio Frequency (RF) sensing system that relies on software defined radio models for in-home activity monitoring. The use case acted as a proof of concept to enable, in the long run, the development of a system that will utilise the capabilities of 5G to look at activity patterns that can support rehabilitation (patient monitoring during rehabilitation), without invading their privacy.

3.2.1 Use Case Description

A non-invasive portable pop-up system was developed, making use of USRP devices, working as Software Defined Radios (SDRs), to extract the channel state information from a continuous stream of multiple subcarriers. Given the channel state information, which describes how the RF-signal propagates between the transmitting and receiving nodes, the variances of amplitude obtained from them are used to infer daily activity patterns via advanced gait and motion analysis. The advantages of using channel state information for activity detection lies in its capability in capturing the small-scale propagation of the signals using the Orthogonal Frequency-Division Multiplexing (OFDM) technique, over multiple subcarriers.

3.2.2 The role of 5G

The proposed RF-sensing system was designed to operate in the 5G-band at 3.75GHz, i.e. a 5G-based sensing system. The system was tested in the university lab as well as in a community housing society based in Alness, Scotland where there are/were active 5G licences that enable the use of this band. Moreover, 5G was also used as a connectivity solution as its speed can enable sensing applications that require split-second decisions, especially health emergencies. Our in-lab RF-sensing system utilised the 5G network to detect such health anomalies, and a latency analysis of the network was performed to help determine the feasibility of integrating actuating systems with the network for future applications. Another key reason to support the choice of 5G is that it offers reliability through network function virtualisation and the ability to set up and tear down services, performance and features as needed without the need for human intervention, which is vital for the design a portable health sensing system.

3.2.3 5G Sensing Trial

The aim of this trial was to investigate the role that 5G can play in revolutionising remote healthcare monitoring systems, particularly using wireless sensing. To do so, the investigation into 5G was twofold:

1. Using 5G frequency for sensing
2. Impact of 5G and its enabling technologies on the overall system performance, particularly when it comes to latency and reporting times

The first point is mining the channel state information from the communication channels whilst operating in the 5G frequency band – at a central frequency of 3.75 GHz and a bandwidth of 20 MHz in our particular use case. Trials were made in the university labs and some results were published in "Nature – Scientific Reports"[5]. The lab trials were a series of experiments to apply the 5G sensing concept for non-invasive activity monitoring. To apply the same concept in the partner community house, a licence was obtained to tune the system for operation at 3.75 GHz. The team was granted approval to operate in this frequency band after a successful application to Ofcom.

Trial Design Aspects

The system deployed in the community house implemented the architecture in Figure 3.6. The following design aspects were considered during the trial:

- Sensing frequency was 3.75 GHz (5G)
- Real-time classification of activities using an intelligent AI algorithm
- Cloud-based operations to assist with the real-time classification
- Incorporation of a Radio Frequency Identification (RFID) testbed to aid with labelling "Sitting" and "Standing" activities.

[5] See: A. M. Ashleibta et al., "5G-enabled contactless multi-user presence and activity detection for independent assisted living," Sci. Rep., vol. 11, no. 1, p. 17590, 2021, doi: 10.1038/s41598-021-96689-7.

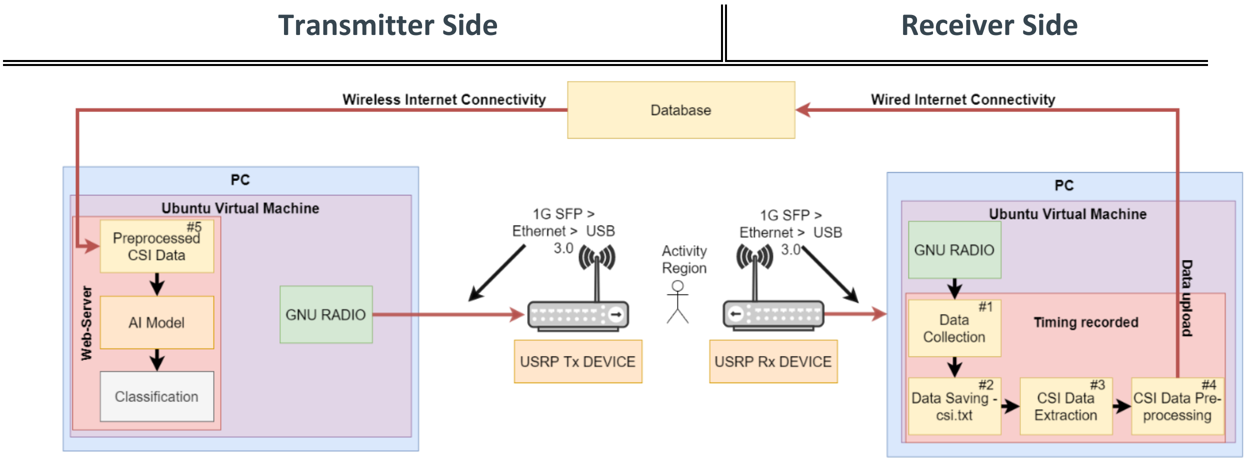


Figure 3.6: System Architecture & Trial Design Diagram.

Trial Setup

The experimental setup is shown in Figure 3.7, where (a) and (b) show the transmitter and receiver USRP devices (bordered in red) positioned in the flat's living room.

(a) Transmitter USRP & RFID testbed *(b) Receiver USRP*

Figure 3.7 Equipment installation in the care home flat for the 5G Sensing Trial

3.2.4 Latency Analysis

The criticality of life-threatening events occurring to individuals living alone calls for an accurate monitoring and reporting system with instant response to critical events. 5G has long promised high data rates and ultra-low latency in its communications and this was put to a test in this project. Our use case implementation demonstrated the impact that 5G can have on the overall system response time and hence its performance.

Our experiments were designed to evaluate, quantitatively, how the introduction of 5G can impact the end-to-end delay/latency of the overall system by capturing the timing of each stage. (See Figure 3.6, where each stage is labelled with a number "#*x*"):

- In the first part of the experiment a standard PC was used to process and classify the collected data against a ML model and a wired connectivity (fibre) was used to upload the data to the database. (See Figure 3.6).
- The second part of the experiment involved the introduction of 5G technology to replace the wired connectivity and then moving some of the stages highlighted in Figure 3.6 to a Multi-Access Edge Computing (MEC) which is an integral part of the 5G network and testbed here at the University of Glasgow. Figure 3.8 shows the change in the system architecture to accommodate the 5G connectivity and the MEC.

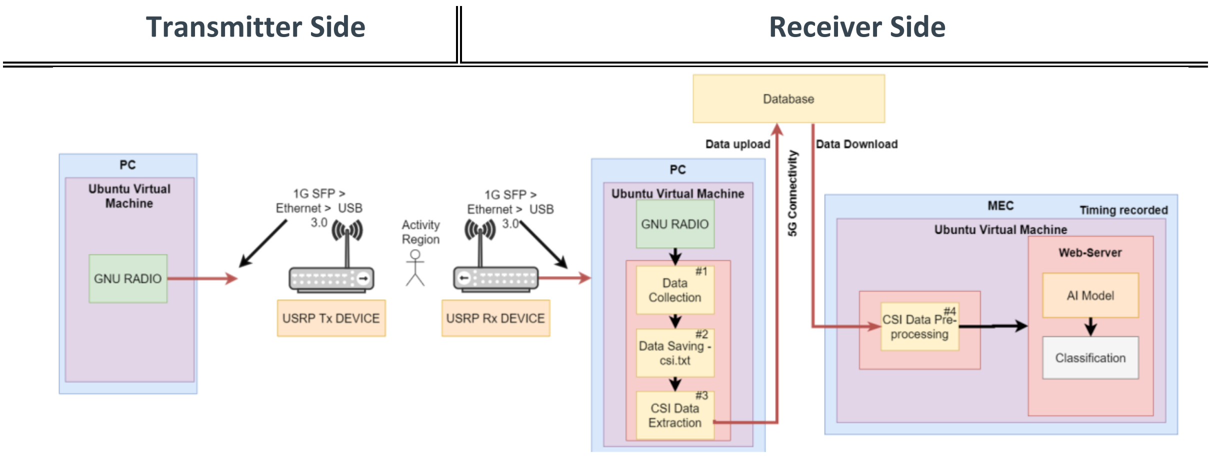


Figure 3.8: MEC experiment: System architecture

As can be seen in Figure 3.8, stages 4 and 5 were moved to MEC side and a 5G connectivity was relied upon in transmitting the data from the receiver side to the database which is then accessed by the MEC. The idea was to mimic a realistic scenario where the activity patterns of a person are being wirelessly captured and transmitted, over 5G, to the core for processing, decision making, and reporting.

The time was recorded for each of the stages (#1 to #5) for both the community house trial and the MEC experiment in the lab (see Figure 3.6 and Figure 3.8). However, the results presented in the section were made from two time stamps; that is, the upload time and the total system time, only. The reason is because the upload time is used to compare a standard fibre connection vs 5G, and the total system time shows the impact of 5G connectivity as well as moving the processing to the MEC. Hence, focusing the evaluation of the 5G connectivity and its enabling technologies. Accordingly, Figure 3.9 and Figure 3.10 show a box-and-whiskers plot of the recorded upload and total time, respectively, for every collected sample.

The samples collect reflect the status of the monitored room; that is, empty, no activity, or activity.

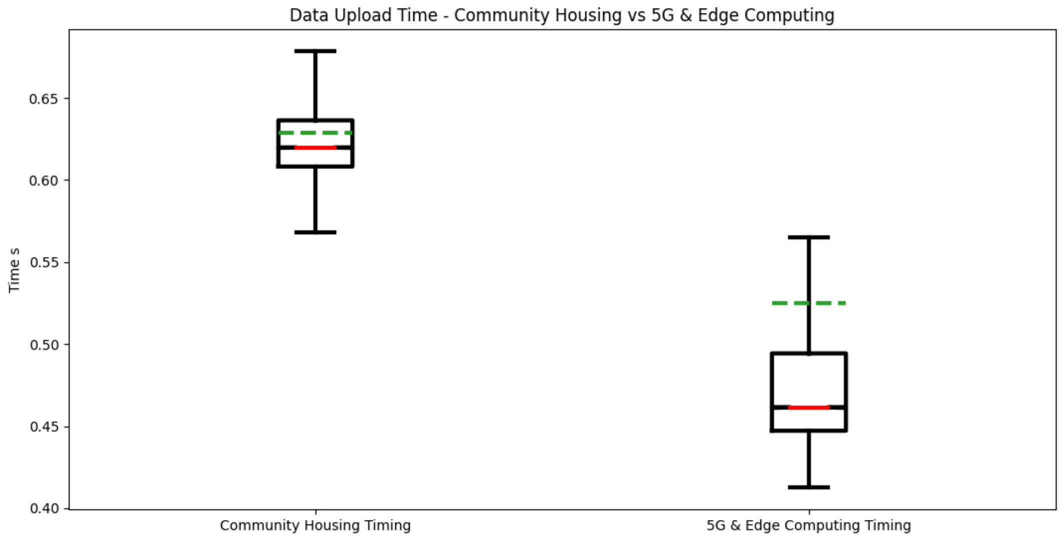


Figure 3.9: Data upload time – Community housing vs 5G & Edge Computing; The green dotted line represents the arithmetic mean (0.63 s vs 0.53 s) and the solid red line represents the Median (0.62 s vs 0.45 s)

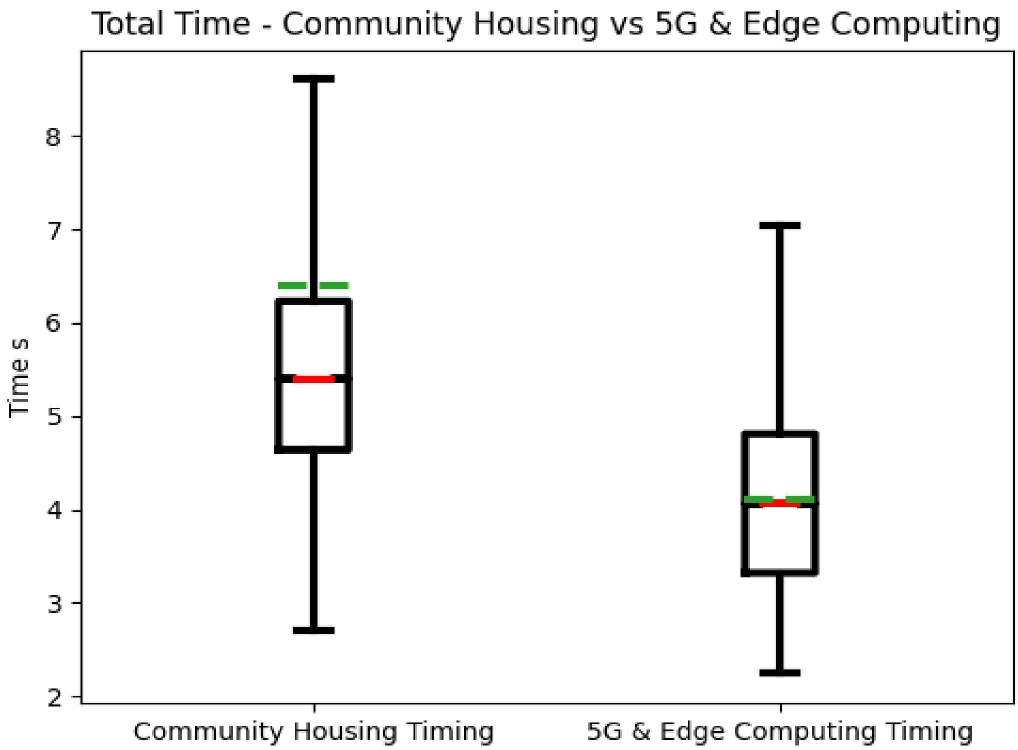


Figure 3.10: Total time – Community housing vs 5G & Edge Computing; The green dotted line represents the arithmetic mean (6.4 s vs 4.1 s) and the solid red line represents the Median (5.5 s vs 3.9 s)

As can be seen in Figure 3.9 and Figure 3.10, the involvement of the 5G testbed, through the introduction of 5G connectivity and the utilisation of the MEC's processing power, has made a significant impact on the recorded timing. The total time, which reflects the time from the moment data is captured until a decision is made and reported, was reduced by more than 35%. The contributors to this reduction are the 5G connectivity which reduced the upload time by more than 15% and the MEC which expedited the pre-processing and classification stages.

The findings from those experiments reflect the capabilities of 5G technology in empowering contactless sensing systems and increasing their reliability, especially when it comes to timely reporting.

3.3 Content-Based Drone Mobility for Pop-Up Mobile

Unmanned Aerial Vehicles (UAVs), also known as 'drones', can be used to boost the availability of a mobile terrestrial network in hard-to-reach areas. This technology is particularly suitable for remote monitoring of such areas for various purposes, such as structural health monitoring, wildfire response, public safety, and emergency monitoring. This section describes a use case in which UAVs are deployed as a 5G pop-up network to extend the coverage of an existing mobile network at outdoor locations where network is not available. The use case makes use of both mmWave and satellite links.

UAVs equipped with an onboard 5G base station establish a wireless mmWave backbone link with a command vehicle that is situated on a line-of-site in the location of interest. The command vehicle is equipped with a satellite dish antenna, which enables backhaul connectivity to the mobile network's core. The location of interest, such as a forest area or a remote coastal location, can therefore be connected to the mobile network by means of the UAV and the satellite link provided by the command vehicle.

For this use case, the University of Surrey developed a drone system equipped with a mobile base station and a millimetre wave antenna, specifically designed for remote monitoring and surveillance. The use-case trials were designed to help us to understand:

(i) the capabilities of the system in terms of the coverage it provides and its communication characteristics;

(ii) how the system responds to typical in-flight events, such as drone manoeuvres and drone flight locations, e.g. altitude and distance to the command centre as well as the angular deviations, all affecting the mmWave link;

(iii) how to further improve the system, e.g. additional hardware and software requirements.

In addition, a software system was developed to enable the processing of information gathered by the drone system to make decisions powered by machine learning algorithms.

3.3.1 Implementing the Trial

As a first step in this direction, 5G Innovation Centre (5GIC) at University of Surrey built a prototype drone communications system that can bring temporary network connectivity to locations not covered by a mobile network. The system can extend network coverage by relaying user mobile traffic to the network's core through the millimetre wave (mmWave) wireless backbone powered by its on-board mmWave communications equipment. The performance of this pop-up mmWave backbone is therefore central to the success of 5G drones.

System architecture of the drone-based pop-up mobile network

The system architecture is illustrated in Figure 3.11. The UAV, i.e. the drone, is equipped with a light-weight software-designed radio (SDR) unit, which can be configured to operate at a given frequency band. The SDR base station weighs 1.7 kg, and consumes 30 W of power when its RF transmitter is active, and has an implementation of an LTE base station (BS) with adjustable LTE operating radio frequency. In system tests, LTE Band 40 (time division duplex - TDD) operating at 2300-2400 MHz was used. At the time of writing, commercial or prototype lightweight 5G gNBs are not available in the market. However, the on-board LTE BS can be replaced with a 5G gNB in the future, without affecting the system architecture.

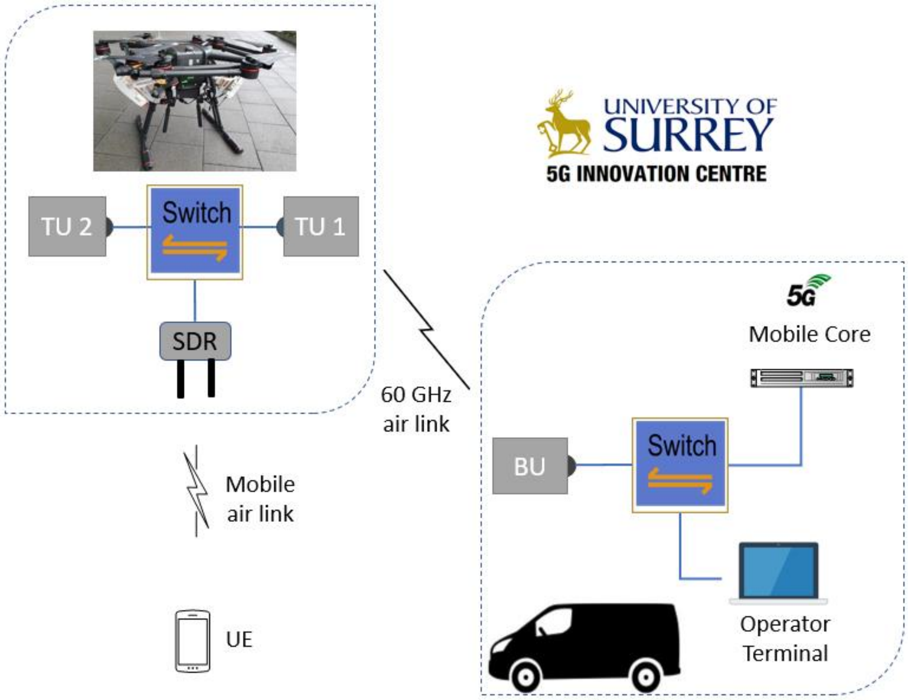


Figure 3.11: System architecture used in use case trials.

The UAV is also equipped with two light-weight mmWave communication units operating at 60 GHz – these are the Terminal Units (TU). The TU units weigh 3 lbs each, and are powered by PoE (Power-over-Ethernet). Each TU can communicate with a paired mmWave unit, called the Base Unit (BU), located at the rooftop of the command vehicle. The TU-BU mmWave link establishes a wireless 60 GHz communications link as a backbone, linking the on-board SDR base station to the mobile core network running in the command vehicle.

Technical Requirements

Figure 3.12 shows some of the terminology that is used to refer to the relative positioning of the drone and the command vehicle. There are various technical requirements for both the system itself and the test environment. These include:

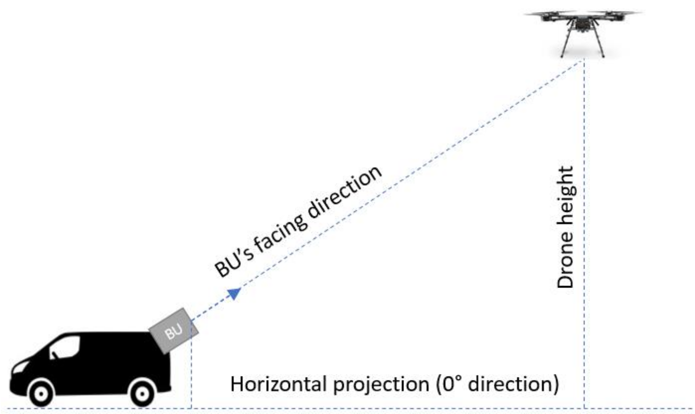


Figure 3.12: Terminology used in drone directionality and positioning.

- **Horizontal projection to the drone**
  - Our tests have shown that an approximate distance of around *120m* horizontal projection to the vehicle location is the maximum range where the link could be kept at stable levels.
- **Drone height**
  - According to legal requirements, a drone distance of at least *50m* to the roads and people around must be kept, which requires at least *40m* of drone height, as the distance to the roads could be *30m* during the tests.
  - According to legal requirements, the drone cannot be at any height higher than *125m*; in field trials the heights up to *90m* were tested. In practice, it was found that heights of up to *90m* were where the UE on the ground could keep its connection to the base station.
- **Alignment of the mmWave units**
  - The on-board TU unit (terminal mmWave unit) must face the control vehicle at all times, so that the wireless link can be kept alive. The tests have shown that this directionality does not have to be perfect, i.e the two mmWave equipment do not have to face each other perfectly. However, the drone must be tilted, especially at the edges of the field and when closer to the vehicle, so that the best link quality can be obtained.

Establishment of the mmWave link

It takes, on average, around *30-40* seconds for IP connectivity to be established between the drone's on-board network and that of the command vehicle. This requires that the drone is first positioned in clear line-of-sight of the command vehicle. In the field trials, we maintained a horizontal projection distance of around *30-40 m* and a height of around *45m*.

Data rate for video streaming applications

Video streaming is one of the most popular applications for drone settings, as it provides remote monitoring and surveillance capabilities. For a sufficiently good quality of video as received at the command vehicle, the data rate needs to be at the levels of at least a few

Mbps. Field tests have shown that the mmWave link can provide sufficient bandwidth for stable video streaming sessions.

3.3.2 Structure and Format of the Trial

The system tests involved the on-board camera and the mmWave backbone. The goal was to observe the performance and operating regions of video streaming from the drone's camera to a test computer in the ground control vehicle, i.e. the van, through the mobile network's mmWave backbone.

Trial Location & Coverage

The trials were carried out in an outdoor field owned by the University of Surrey at its Manor Park campus.

Figure 3.13: Test field in Manor Park campus of the University of Surrey. Control vehicle is parked in a bay towards the field. The approximate boundaries of the test area are designated by white lines (not to scale). Numbers designate a subset of text locations where the drone is kept steady.

Drone locations during the test

Figure 3.14 illustrates the approximate test locations. At each test location, the drone was kept stationary while *10* video bit rate measurements were taken. The ground control vehicle was parked at a parking bay by a road near the test field, and the base mmWave unit faced towards locations *0-3*.

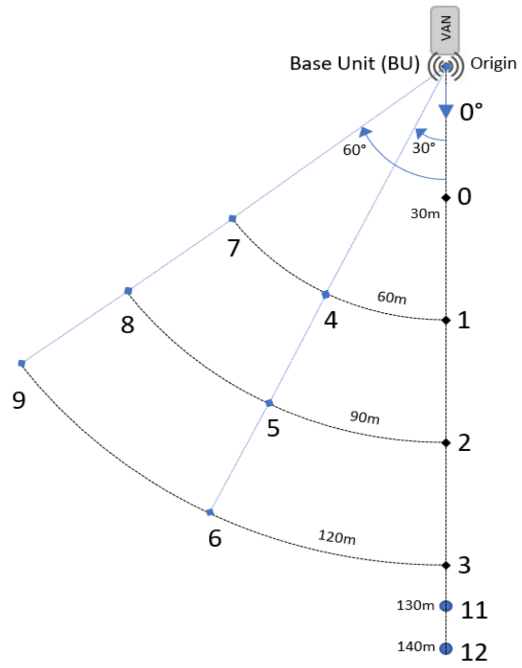


Figure 3.14: Test locations for use-case trials. Numbers indicate measurement locations where the drone was kept steady while multiple measurements were taken at the ground control vehicle (aka VAN).

3.3.3 Trial Results

To assess the mmWave wireless backbone, we used video streaming traffic. The IP camera on-board the drone collected video feed and then sent it to a controller PC at the command vehicle.

Figure 3.15 presents the average and standard deviation of received video bit rate at the ground control vehicle, measured at different drone heights (with increments of *5m*) at three different locations (locations *0*, *2* and *3*) at horizontal projection distances of *30m*, *90m*, and *120m* to the command vehicle. For the case of *30m* distance, the mmWave link was broken at heights above *50m*, as the drone was simply out of the coverage of the BU's main beam. For the *30m* distance point, the best height was observed to be *45m*, where the highest average value and lowest standard deviation were achieved. As the drone was taken further away to *90m* from the BU, this best operating height also increased to *55m*. At an even further location of *120m* away from the BU, the best video quality was achieved at *65m* height. This is due to the directionality of the BU's radio beam and the facing direction of the BU towards the sky.

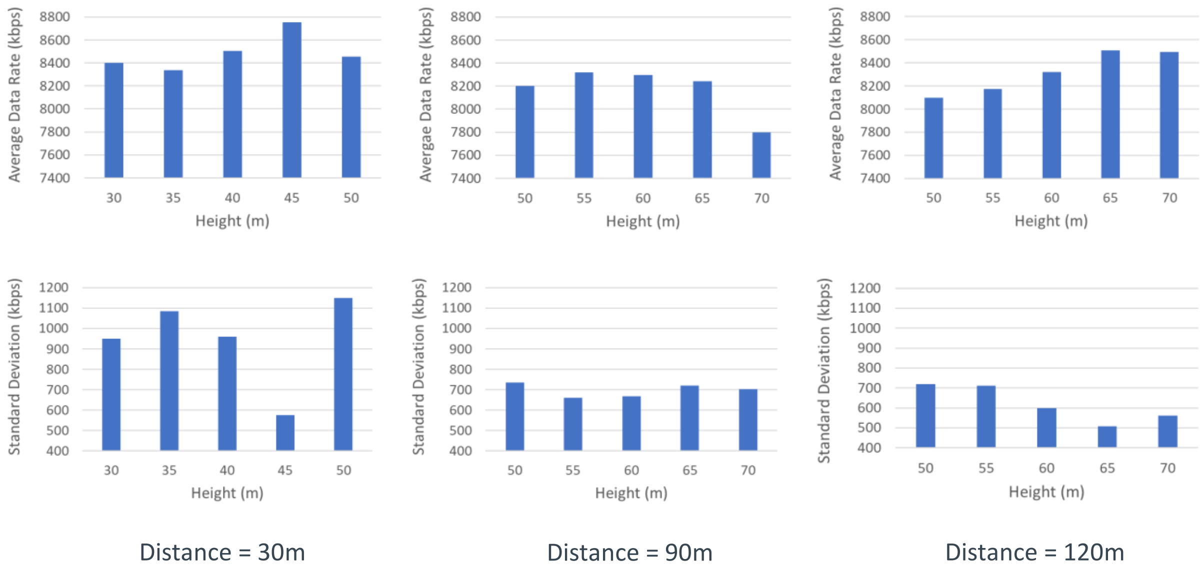


Figure 3.15: Received video bit rate at different heights.

At around *30m* from the van, a drone height of *45m* gives the best input rate values, still keeping a direct distance of more than *50m* to the van, hence operating within regulations.

Figure 3.16 illustrates the best operating horizontal projection distance (where the highest video bitrate is achieved) when the drone's angular location to the command vehicle is different. The drone height is kept at *50m* above the ground. As can be observed, when the drone location directly faces the command vehicle, i.e. *0°* angle (see Figure 3.14), this distance is around *120-130m*, and as the drone approaches towards the edge of the covered area, the best performance can be achieved at closer locations to the command vehicle, first at *90m* when the angular deviation is *30°*, and then at *60m* when the angular deviation is *60°*. It must be noted that different values would be obtained according to how the BU unit is set up at the rooftop of the command vehicle: if the BU faces higher towards the sky, the best operation distances would decrease when the drone height is kept constant.

Overall, the results in Figure 3.15 and Figure 3.16 demonstrate that the system can effectively cover an angular range of up to *60°* (a total angular width of *120°*, where the BU faces the *0°* direction). The achieved data rate depends on a number of factors – mainly the drone height, the horizontal projection to the command vehicle, and the angular position of the drone to the facing direction of the BU mmWave unit at the command vehicle.

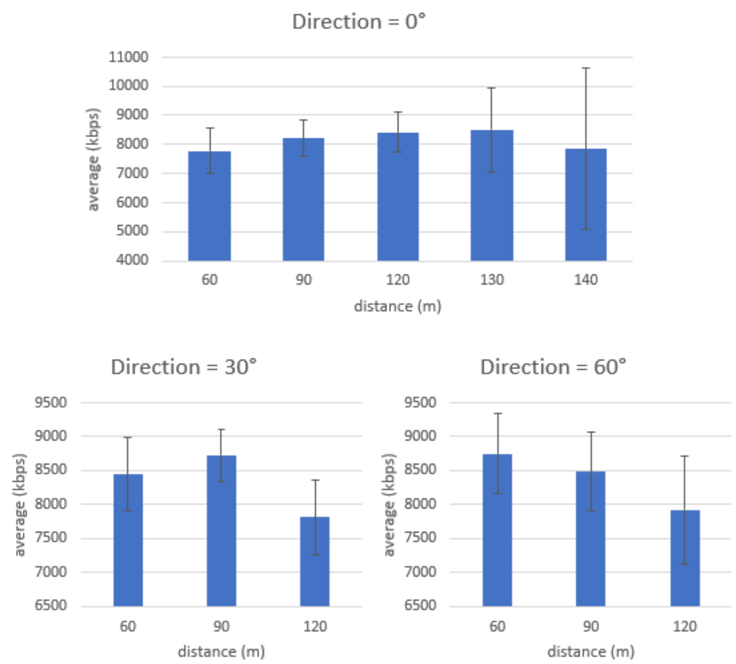


Figure 3.16: Effect of the angular deviation of the drone's location to the 0° angular direction (see Figure 3.14).

3.3.4 Machine Learning Support for Drone Operations

Besides the system tests in the open-field, the trials also involved development of a software system that enables processing of information gathered by the drone system to make decisions powered by machine learning algorithms. These decisions can be either for automating the drone flight according to a pre-planned itinerary, whilst avoiding undesired situations such as collisions with objects (e.g trees, other drones, etc.), or for processing the data collected by the drone for an application program to consume.

The pre-planned flight plan would include the points of interest in the field where the drone is to stay steady whilst data is being collected, i.e. video streaming input to the command vehicle. This would then be complemented by a data analytics engine running at the control vehicle (or on-board the drone on a companion computer). The engine processes incoming video images, and identifies the context of the drone, and then makes decisions to re-position the drone by means of moving it at the same height, changing the drone height, or flipping it so that camera can be aligned with another direction of view.

3.3.5 Summary & Conclusion

A drone communications system has been developed, where a drone is equipped with a pair of mmWave antennae that establish a wireless backbone link to the command vehicle, as well as a base station unit so that user equipment (UE) can get connected to the mobile core. The drone is also equipped with an IP camera, which is used to stream video capture of the location of interest back to the command vehicle.

The trials were focused on evaluating the mmWave backbone, the onboard equipment carried by the drone, and the performance of the mobile link between the UE and the onboard base station. The test goal was to observe the performance and operating regions of video streaming from the drone's camera to a test computer in the ground control vehicle, i.e. the van, through the mobile network's mmWave backbone.

Overall, the field results demonstrate that the system can effectively cover an angular range of up to *60°* (total angular width of *120°*, where the BU faces the *0°* direction.). The achieved data rate depends on a number of factors – mainly the drone height, the horizontal projection to the command vehicle, and the angular position of the drone to the facing direction of the BU mmWave unit at the command vehicle.

Moreover, we have developed a software system that enables the processing of information gathered by the drone system to make decisions powered by machine learning algorithms. These decisions can be either for automating the drone flight according to a pre-planned itinerary, whilst avoiding undesired situations such as collisions with objects in the field (e.g. trees, other drones, etc.), or for processing the data collected by the drone for an application program to consume.

The trials of the drone-based communication system demonstrated that it is an effective solution for providing a pop-up mobile network. The technology could deliver urgent and temporary network connectivity in various scenarios, including natural disaster scenarios, such as a forest fire or mountain rescue, which would require a pop-up network to be set up and relay data from remote hard-to-reach locations. Similarly, it could be used in emergency scenarios in which a large-scale activity is necessary, e.g. for real-time asset tracking; multiple drones could be used to cover an area over land or sea. In addition, public safety services can benefit from the drone-based pop-up mobile network to help them track criminal activity.

However, some practical limitations affected the testing capability of the drone-based pop-up mobile network. The first main point of consideration was the proximity regulation: to comply with this regulation, the drone had to be at least *50m* away from the public. Also, the directionality and range of the mmWave antenna played a key role in choosing the section of the field in which tests could cover. The tests revealed a maximum range of around *120m* when the drone was directly facing the control vehicle; beyond this range, video streaming stopped. Furthermore, due to limited battery time, it was impractical to take measurements in a grid of high granularity. Drone flight positioning is also prone to atmospheric conditions, mainly winds and gusts.

3.4 Orkney Trials

A number of trialists were involved in 5G New Thinking trials across three island communities in Orkney. The use case focused on the provision of better communications and data rates to the communities who are currently underserved by the local incumbent.

3.4.1 Implementing the Trial

Trialists were recruited in the areas of:

- Hoy - Lyness and Longhope;
- Westray (Kirkbrae & Rapness);
- Papa Westray (whole island group).

All of these communities were known to have poor broadband and mobile coverage.

Each local Island group has community council groups/bodies that have represention from locals within each community (farmers, minister, health workers, professionals, retirees etc.), and are attend by Local Authority Community Councillors and the Community Liaison Office at Orkney Islands Council. They all have a vested interest in supporting their communities, and they aim to ensure that there is a small management team there to deal with a number of factors, such as local policies, national policies, projects/newsletters, complaints, investments (external/internal), and local government liaison.

In each of the three trial locations, communication is achieved predominantly via newsletters and flyers posted to every household. Newsletters are developed by locals for locals, and all communities rely on these for local contact and news.

To implement the 5GNT trial, a request was made by project partner and local ISP Cloudnet IT Solutions to each of the community councils, seeking trialists. Background information was provided to these groups, and they were asked to put this information into the next newsletter asking for anyone interested to log a request.

An online registration form was created, in compliance with GDPR.

3.4.2 Trialists

68 trialists were selected in total across the three island communities.

One trialist was a local school on Papa Westray that obtained an autonomous vehicle which the children named “Max”. This device was provided to the school to educate the children and to explore how autonomous vehicles could work in a rural environment. Max was funded by HITRANS and supported by Highlands and Islands Enterprise.

Another trialist was a remote island clinic/surgery with approximately 120 registered patients. The clinic was equipped with video-conferencing facilities, enabled by the 5G network, to allow patients to engage in remote video-consultations with off-island GPs and mainland hospital consultants, and to allow the clinic’s nursing staff to engage with NHS staff in other locations. This was expected to enable a reduction in the number of off-island trips by patients, and a reduction in the number of consultations cancelled due, for example, to bad weather preventing the doctor from being able to travel in person to the island for the weekly surgery.

3.4.3 Trialist Surveys & Questionnaires

As part of the trial, a survey was carried out on the properties during the installation process and at other times during the trial. The survey considered technical aspects such as installation times and ease of installation depending on building construction, as well as user experience-related aspects such as uses, usage patterns, and satisfaction.

Achievable data rates are dependent on may factors, including geographic terrain, distance from basestation, etc. The 5G New Thinking testbed network was able to provide up to 130 Mbit/s in the downlink and 50 Mbit/s in the uplink. By comparison, some of the trialists, particularly those in Cluster 2, were able to receive only one or two hundred kbit/s second with their existing provider, and of 40 respondents surveyed prior to the trial, all 40 indicated that they were not satisfied with their existing broadband provision.

The vast majority of trialists (90% of 37 respondents) were satisfied with the 5G New Thinking broadband. (Those who weren’t were on the very edge of cell coverage.) Not many people are prepared to pay above £34 per month for a broadband service, however. Cited reasons included:

- “Rural communities already pay more for living remotely – the cost of living is higher, and people typically cannot afford to pay for a better service if it costs more”;
- “Why should we pay more, when we see national adverts stating less for higher bandwidth?”

Concrete data for the clinic/surgery is not available. However, projections based on local observation suggest that up to 75 off-island trips per year could be avoided by the 5G-enabled video-conferencing facility. The cost savings associated with avoiding a particular journey depend on the specific details of that particular journey, but it is estimated that annual savings could potentially be up to £25,000. It is also projected that some 10-20 consultations could be saved from cancellation each year by holding them as video-conference meetings when face-to-face consultations are not possible.

3.5 Balquidder Trial

In order to support and inform the development of the 5GNT Rural Toolkit, a testbed network was designed and planned for deployment in Balquhidder, a village situated near the northern tip of Loch Lomond, with a population of just over 600 people. (See Figure 3.17.)

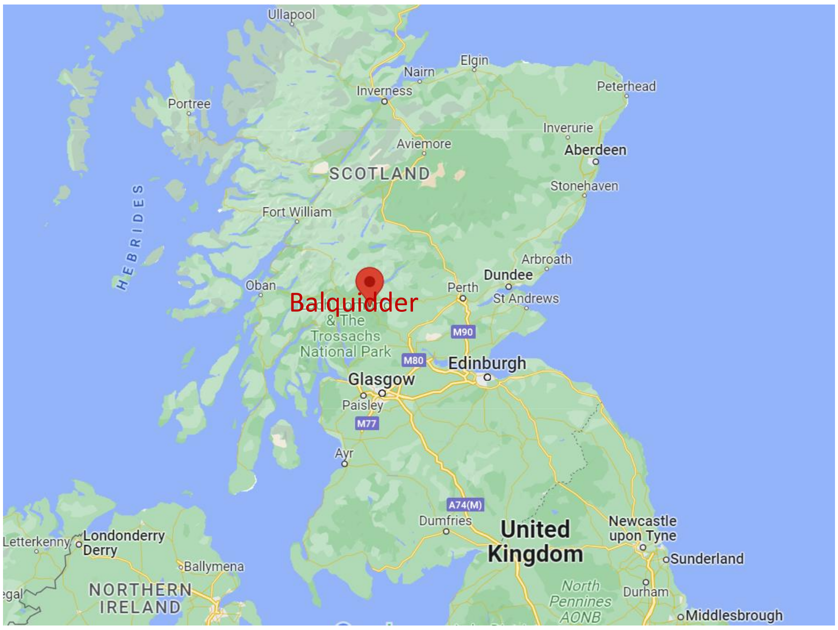


Figure 3.17: Balquidder is situated approximately 50 km north of Glasgow.

Local ISP, Bogons, had already built a community-supported FTTH network in the village, laying around 40 km of fibre to approximately 180 premises, providing 1 Gbps symmetrical connectivity to each premise with a simple path to 10 Gbps. This gave locals very good indoor connectivity; however outdoor connectivity remains very poor, as Balquhidder has little-to-no mobile coverage – mostly 2G with some patchy (and unreliable) EE 4G in the east where there is Emergency Services Network (ESN) coverage.

With the above in mind, this Use Case Trial therefore aimed to explore the potential for providing 5G mobile connectivity in Balquidder.

The initial idea was to implement a 5G SA **Neutral Host** network. However, it became clear that this would take over a year and would potentially require more funds than were available to gain equipment approval and Neutral Host integration. Furthermore, testing showed limited availability of 5G SA phones at the time, and those mostly had their 5G SA capability MNO network locked.

As an alternative, a **National Roaming** trial was decided upon, which would permit 5G NSA operation using a combination of equipment from Wavemobile Ltd and the University of Strathclyde.

3.5.1 Design Principles

Bogons' extensive prior experience of providing fibre connectivity to small communities, with limited available funds and effort, led to the following principles being adopted for the design:

- As the village is situated within a national park, it would be difficult to obtain planning consent for large telecoms towers. Therefore, smaller, telephone-pole-based masts were used instead. (These blend in better with the local tree cover, and they can be easily installed by the local community, at low cost and without the need for major equipment or land engineering activities.)
- To further reduce visual impact, radios would be housed in cabinets at the bottom of the poles rather than at the tops of the poles.
- Direct dark fibre access permitted reduced equipment at the mast sites, with the core in a remote datacentre (Bogons' bunker some 35km away).
- Due to typical Scottish topography, more sites were needed to provide coverage of the area – this is another reason to make each mast as cheap as possible. Network equipment was reduced to a single fibre-attached switch plus the radios.

3.5.2 Local Access Licences (LALs)

After some beta testing, the licence tool became available in autumn 2021 and was used to generate 1800 MHz and 750 MHz licence applications. Some considerable time was lost with Ofcom who had difficulty, due to file size limitations in their systems and their pdf readers rendering the pages incorrectly, and similarly in their communication with O2, whose spectrum we had applied to use. This was resolved towards the end of 2021 by sending the documents as a jpeg image for each page. O2 turned around the application reasonably quickly, in just over two months; they declined the 750 MHz application but approved the 1800 MHz application. They suggested that a short-term Innovation and Trial licence could be issued for 750 MHz instead. However, while this would enable testing, it would preclude ongoing operation.

Ofcom issued the 1800 MHz LAL on 31st March 2022 – the final day of the project. The Innovation & Trial licence was not ready until mid-April, by which time the project had formally closed.

3.5.3 Shared Access Licences (SALs)

The addition of 4G fall-back to enable the use of 5G NSA required a 4G 1880 MHz SAL. This arrived quite quickly and enabled that part of the network to be deployed and operational from December 2021. This carried traffic through to the end of the project while waiting for a 5G network to become available.

The one active 4G site served 26,575 unique visitors whose MNOs were not providing service in that location:

O2:	6,688
Vodafone:	4,990
Three:	2,598
EE:	3,997
Rest Of World:	8,302
TOTAL:	**26,575**

A sizeable number were international visitors to the area, for whom coverage is essential.

Data passed over the network was 313 GB.

3.5.4 User Trials

As a consequence of the challenges in securing the required LAL spectrum licences in accordance with the project timeline, we did not have time to run user trials before project closure. Bogons hopes to complete testing of the 5G network with the University of Strathclyde and Wavemobile under a short-term test licence. Bogons will aim to deploy Wavemobile 5G radios to provide an ongoing service later in 2023, and will consider the feasibility of licensing an alternative spectrum band for this.

3.5.5 Some Reflections

The timescale of this project was already tight, with the need to wait for other areas to progress their work before this particular work package could start. The Covid-19 pandemic and global supply chain issues compounded this, delaying on-site work and equipment acquisition.

It took more than 7 months to conclude the LAL application. This would have made procuring equipment to match the licensed bands on time impossible, regardless of supplier availability. If purchased at risk, it would have resulted in unusable radios, as our LAL application in the 700 MHz band was rejected.

It would thus seem reasonable, therefore, that future deployments should:

- Plan their builds to take a lot longer, especially if seeking to use Local Access Licences.
- Obtain their LAL first, and expect it to take 6 to 9 months – or longer if it has to be resubmitted requesting alternative spectrum.

- Expect a change of spectrum if the MNO has not already indicated that the initial choice is available. (This is likely to also have an impact on coverage, site locations, etc.)
- Purchase equipment and build sites only once the LAL is secured.
- Plan for a shorter amortisation/return period. The LAL is for 3 years maximum by default, and a year of that may be lost in building the network, thus the business case has to work over as little as 2 years.

The risk of LAL withdrawal is significant. These networks are not cheap to build and only having use for 2 to 3 years will likely make them infeasible without external grant funding.

4 Spectrum Access: Approaches and Mechanisms

A fundamental resource that is required for the deployment of mobile and wireless networks, regardless of intended application, is spectrum. Spectral requirements differ depending on the desired network implementation, with different access mechanisms in place for different frequency bands.

For spectrum that supports mobile broadband networks in the UK, a licence is required from the Office of Communications (Ofcom), the UK's communications regulator, to authorise operation. Such licences are typically obtained via a spectrum auction, and this has historically cost in the range of hundreds of millions of pounds. This significant capital expenditure (CAPEX) limits the potential auction participants, and hence network operators, to large entities with existing capital or infrastructure to leverage.

In December 2018, Ofcom released a consultation outlining two key proposals to enable shared spectrum in the UK. The aim of these changes was to promote innovation and enable new services by allowing organisations to access frequency bands with an existing, developed equipment ecosystem with greater control over the network security, resilience, and reliability. Some of the envisaged example applications included deployment of private networks for coverage and Internet of Things (IoT) solutions, rural broadband, and Fixed Wireless Access (FWA) services and addressing indoor or outdoor connectivity not-spots.

Under the proposed changes new user users would be able to apply for a localised licence in defined shared access bands but would also be able to apply for access to any spectrum band that was covered by the mobile trading regulations. These changes were finalised in a July 2019 statement, with applications for access to the shared bands beginning in 2020.

There are essentially two flavours of spectrum sharing under the framework:

- Shared Access Licences (SALs): These allow localised access to specific 'Shared Access' spectrum bands.
- Local Access Licences (LALs): These allow localised access to mobile operator spectrum in areas where it is not currently in use, nor planned for use in the near future, by the national licence holder, referred to as the Incumbent.

4.1 Shared Access Licences (SALs)

Shared Access Licences have been enabled for the 1800 MHz, 2300 MHz, and 3.8-4.2 GHz bands on a first come first-serve basis. A portion of the lower 26 GHz band has also been designated as a shared band, for indoor use only.

Different deployment scenarios and applications are permitted for each frequency band. These are summarised in Table 4.1.

Application	1800 MHz	2300 MHz	3.8-4.2 GHz	Lower 26 GHz
Private Network	Yes - Narrowband	Yes	Yes	Yes - Indoor only.
Mobile Coverage (Rural)	Yes	Certain Locations	No	No
Mobile Coverage (Indoor)	Yes	Yes	No	Yes
Fixed Wireless Access	No	No	Yes	Yes

Table 4.1: Permitted Deployments for Shared Access Licence Scenarios.

4.1.1 The 1800 MHz, 2300 and 3.8-4.2 GHz Bands

The "*three shared access bands*" refer to the frequency ranges 2390-2400 MHz, 3800-4200 MHz, and 1781.7-1785 MHz paired with 1876.7-1880 MHz. These frequency ranges overlap with standard 3GPP operating bands for LTE and 5G New Radio (5GNR).

The 1800 MHz Band

The 1800 MHz band is illustrated in Figure 4.1. The 3.3 MHz of shared access uplink spectrum and the corresponding 3.3 MHz of shared access downlink spectrum sit within LTE Band 3 and NR Band 3, both of which operate in FDD mode.

The minimum possible channel bandwidth in LTE B3 is 1.4 MHz, so LTE devices can, in theory, operate within the 3.3 MHz limit provided they are configured accordingly.[6] However, in Band N3 the minimum channel bandwidth is 5 MHz, which means that 5G devices will not be able to operate under the sharing framework in the 1800 MHz band, as the maximum operating bandwidth allowed for shared access licences in this band is 3.3 MHz.

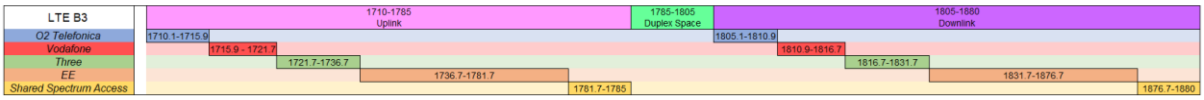


Figure 4.1: The 1800 MHz Band.

The 2300 MHz Band

The 2300 MHz spectrum band is illustrated in Figure 4.2. TDD arrangements exist in LTE Band 40 and NR Band 40, both spanning 2300-2400 MHz. The minimum channel bandwidth supported in both bands is 5 MHz, which makes both applicable candidates for deployment using shared access licences. (The minimum amount of spectrum that can be applied for under the sharing framework in this band is 10 MHz.)

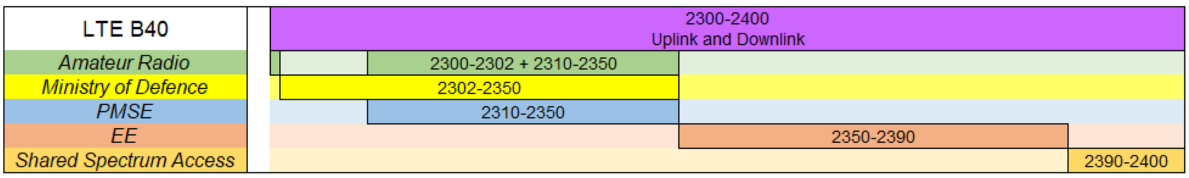


Figure 4.2: The 2300 MHz Band.

[6] In practice, however, we haven't yet managed to find any handsets that actually work with a 1.4 MHz channel bandwidth, and, furthermore, not all handsets work with a 3 MHz bandwidth.

The 3.8-4.2 GHz Band

The 3800-4200 MHz spectrum band, illustrated in Figure 4.3, is covered by NR Band 77, which is also a TDD arrangement. There are currently no defined LTE bands that overlap with this frequency range. Although other options are available in the technical standard, the sharing framework only permits carrier bandwidths of 10, 20 30, 40, 50, 60, 80, and 100 MHz.

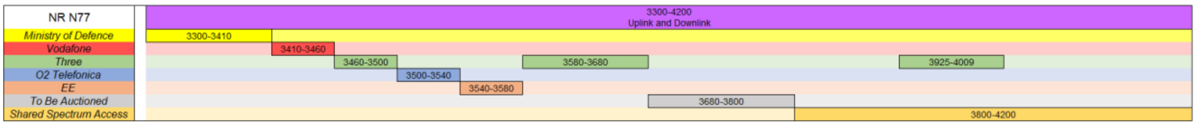


Figure 4.3: The 3800-4200 MHz (3.8-4.2 GHz) Band.

4.1.2 The 26 GHz Band

Between the release of Ofcom's December 2018 consultation and July 2019 statement, the lower portion of the 26 GHz band was added to the sharing framework. This framework allows for access to 2.25 GHz of spectrum between 24.25-26.5 GHz, for indoor applications.

While the full 26 GHz band, 24.25-27.5 GHz, overlaps with two 3GPP-defined NR bands, the spectrum covered by this framework involves only NR Band 258. This TDD arrangement spans the 24.25-27.5 GHz range and allows for channel bandwidths of 50, 100, 200, or 400 MHz, although the latter is not permitted under the sharing framework.

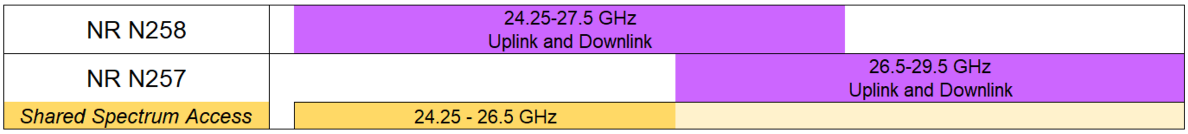


Figure 4.4: The lower 26 GHz Shared Access Band.

4.2 Local Access Licences (LAL)

The updated Ofcom policy allows new users to access spectrum covered by the Mobile Trading Regulations in areas where it is not currently being used by, and is not planned for use by, the national licence holder, referred to as the Incumbent. This creates a geographically constrained local access method for the 800 MHz, 900MHz, 1400 MHz, 1800 MHz, 1900 MHz, 2100 MHz, 2300 MHz, 2600 MHz, and 3.5 GHz bands.

The framework has been designed to create a simplified approach for new users to access these bands by applying directly to Ofcom for authorisation, though access approval is coordinated with the relevant Incumbent. As new bands are introduced into the Mobile Trading Regulations, these will also be included under the framework. However, newly awarded bands would not be eligible for a significant period, to give the new licence holders time to determine deployment strategies.

Following a successful application, the default licence period of 3 years can be issued for a one-off cost of £950. Longer, or shorter, durations could be granted subject to discussion with the Incumbent and Ofcom. It is expected that the spectrum most likely to be shared will be in remote and rural locations and used for the provision of private networks supplementing coverage from the existing mobile network operators.

The technical conditions for these Local Access licences are considered on a case-by-case basis. While it is expected that applicants will deploy existing mobile technologies to create deployments similar to those of the Incumbent, the licence would generally permit alternative implementations.

4.3 Limitations of Current Regulation and Access Mechanisms

The Shared Access and Local Access frameworks have been a significant step in widening access to spectrum. However, there are some factors which present challenges to potential applicants or impact the operation and business case of a network deployment, to a degree that could hinder uptake.

4.3.1 Technical Requirements of Application Process

The low power Shared Access Licence allows for unlimited basestation deployments within an area of 50m radius while medium power licences are allocated on a per basestation basis. Both scenarios will require potentially quite accurate planning and propagation simulation to ensure the intended network coverage requirements will be achievable before submission of the licence locations.

This would be a significant challenge for a Local Authority or community to calculate and plan for without input from external consultants, as the tools to carry out this kind of modelling are typically specialised or commercial.

The application process for a LAL has significantly more requirements than for a SAL, due to the increase in pre-coordination work (coverage predictions, interference analysis, field data collection) that needs to be performed to execute a credible application and receive support from the Incumbent.

These pre-coordination demands are partly reflected in the success rate of Local Licence applications since becoming available in July 2019. A recent Freedom of Information (FOI) submission[7] indicates that of 9 total applications, 4 have been unsuccessful.

The development activities for the 5GNT toolkit aimed to simplify the application process, help to manage the licence once acquired, and help to identify any disqualifying issues that would lead to application rejection.

A primary objective was the development of software to reduce the pre-coordination work required to be performed by the Local Access applicant. A further objective was to demonstrate the feasibility of automating the process and making recommendations to Ofcom to better facilitate the automation.

4.3.2 Height and Power Restrictions

The technical conditions for the Local Access Licence are considered on a case-by-case basis. On the other hand, the current height and power limits of both variants of Shared Access Licences are as shown in Table 4.2. The medium power licence is restricted to applications in rural areas, while the low power licence can be more flexible as far as location is concerned, though Ofcom reserves the right to waive restrictions.

[7] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0028/192790/5g-mobile-spectrum-licences.pdf

Under both Shared Access Licence types, the maximum height for an outdoor transmitting antenna is 10m above ground level (AGL). The maximum transmit power of a basestation varies with licence type and, in the case of the 3.8-4.2 GHz band, the carrier bandwidth.

The practical implemented carrier bandwidth will vary with the deployment application, as outlined in Table 4.2, and the corresponding data requirements. In any case, the highest permitted power of a basestation is 42 dBm EIRP, and that of a client device, referred to as a station, is 35 dBm EIRP.

Licence Type	Condition	Parameters (by band)			
		1800 MHz	2300 MHz	3.8-4.2 GHz	Lower 26 GHz
Low Power	Permitted Deployment	Indoor and Outdoor. Outdoor antenna limited to 10m AGL	Likely to only be available Indoor. Outdoor antenna limited to 10m AGL	Indoor and Outdoor. Outdoor antenna limited to 10m AGL	Indoor only.
	Max. Basestation Power	24 dBm / carrier [1] (up to 3 MHz)	24 dBm / carrier [1] (up to 10 MHz)	24 dBm / carrier [1] for carriers ≤ 20 MHz 18 dBm / 5 MHz [1] for carriers ≥ 20 MHz	23 dBm / 200 MHz [2]
	Max. Terminal Power (EIRP[1] for fixed, TRP[2] for mobile and nomadic)	23 dBm	25 dBm	28 dBm	23 dBm
Medium Power	Permitted Deployment	Rural Areas Outdoor antenna limited to 10m AGL	Rural Areas Outdoor antenna limited to 10m AGL	Rural Areas	N/A
	Max. Basestation Power	42 dBm / carrier [1] (up to 3 MHz)	42 dBm / carrier [1] (up to 10 MHz)	42 dBm / carrier [1] for carriers ≤ 20 MHz 36 dBm / 5 MHz [1] for carriers ≥ 20 MHz	N/A
	Max. Terminal Power (EIRP[1] for fixed, TRP[2] for mobile and nomadic)	23 dBm	25 dBm	28 dBm (TRP) 35 dBm / 5 MHz (EIRP)	N/A

1. EIRP - The equivalent isotropic radiated power (EIRP) is the product of transmit power and antenna gain in a specific direction.
2. TRP – Total radiated power (TRP), for terminal station emission limits, is defined as the integral of the power transmitted over the entire radiation sphere of the transmitter.

Table 4.2: Height and Power Permissions for both Shared Access Licences.

The heights and transmit powers outlined in Table 4.2 primarily facilitate small-cell deployments. Even under the terms of the medium power licence, it will be technically challenging to achieve significant macro coverage in rural locations while working within the confines of these limitations.

Assuming an appropriate link power budget can be achieved, improving basestation coverage reduces the number of units needed to serve an area. This helps with network planning and design, and in turn will reduce the installation capital expenditure (CAPEX) and ongoing operational expenditure (OPEX). This will influence the business case of potential network deployments, which will impact the uptake of licence applications.

Increasing the permitted height and transmit power would improve the achievable macro coverage and help to improve the applicability of the low- and medium-power SAL for rural deployments.

This suggestion does not come without precedent. In 2012, TV White Space (TVWS) regulations were established to improve rural connectivity options using shared and dynamic spectrum techniques. As with the SAL and LAL, these frequencies were available under geographic restrictions with a primary spectrum user, or *incumbent*, operating as spectral neighbours. In the case of TVWS, the incumbent users are the Digital Television Transmitters (DTT) and Programme Making and Special Events (PMSE) equipment.

The US Federal Communications Commission (FCC) has recently made several amendments to its initial regulations governing the operation and deployment of TVWS equipment, primarily intended to aid rural connectivity.

In December 2015, in supplement to the announced UHF spectrum auction, technical rulesets were implemented to allow for licence-exempt operation in the repackaged TV bands, unused 600 MHz service spectrum, and the 600 MHz duplex space.

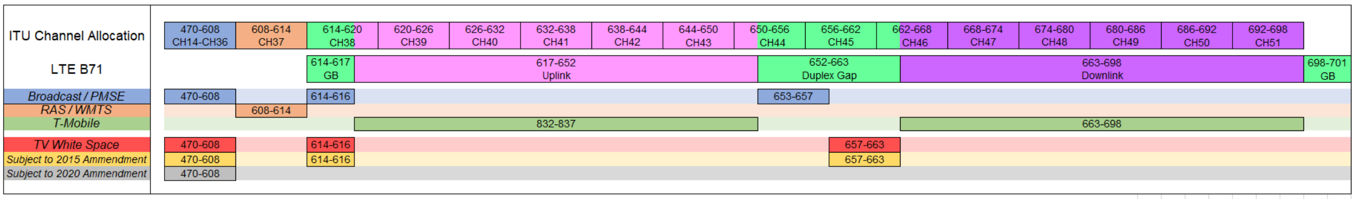


Figure 4.5: The FCC TVWS Spectrum

To help promote rural deployments the maximum operating power of 4W (36 dBm) EIRP was increased to 10W (40 dBm) EIRP in areas where the spectrum is *"less congested"* – where less than half of the band is occupied. It also allowed portable White Space Devices (WSD) to operate spectrally closer to incumbent transmissions.

In March 2019, amendments to the regulation increased the permitted antenna height in less congested areas from 30m to 100m, although the height above average terrain (HAAT) remained limited to 250m.

In February 2020, based on an initial petition from Microsoft, further changes to the rules were implemented to allow for additional flexibility for WSD operating in the TV bands. These updates were primarily aimed at aiding deployment of rural broadband solutions and increasing applicability for Internet of Things (IoT) operations.

To that end, the updated regulations permit higher power operations, up to 16W (42 dBm), and higher antenna HAAT, up to 500m, in less congested areas for fixed WSD.

This change will primarily benefit fixed wireless access (FWA) style applications. An increase in antenna height and transmit power will significantly improve the coverage area of a basestation WSD. However, this will only result in improved connectivity if the client station, or customer premise equipment (CPE), has sufficient capability to also communicate with the basestation.

The 2020 notice of proposed rulemaking (NPRM) also outlines the concept of "geo-fenced" areas, i.e., defined geographic locations where mobile WSDs can transmit at higher power levels than would normally be available for portable units. Within these geographic boundaries, mobile WSDs would operate analogous to fixed WSDs, with additional restrictions to prevent harmful interference to incumbents.

These changes are intended to facilitate high mobility applications, such as connected vehicles or livestock tracking. Under prior regulations, these kinds of use cases have been limited by the lower transmit power and antenna heights permitted to mobile WSDs.

In addition, to help support narrowband IoT applications, a new category of WSD was created: *"narrowband white space device"*, which operates over a reduced carrier bandwidth and with reduced restrictions on the emission power spectral density (PSD). These changes are intended to increase the scope of use cases enabled by TVWS shared spectrum to include low-power wide area network (LPWAN) applications.

While the spectrum access mechanisms and incumbents differ between SAL/LAL and TVWS, the applications targeted by both sets of regulations have considerable overlap.

4.3.3 Business Model Restrictions

A significant challenge, which is a fundamental part of all aspects of the Local Access framework, is that engagement with the Incumbent is omnipresent before, during, and after the licensing process, with deployments greatly benefiting from aligning the business models of the local network and the incumbent MNO. Having the licence longevity dependent on co-operation of the incumbent could impact the business case for a network and be a deterrent to potential applicants.

While initial applications are checked and validated by Ofcom prior to formal Incumbent input, the work required to create a suitable licence application will be made significantly more complicated without prior engagement with the relevant Incumbent.

This is largely a result of the commercial sensitivity surrounding exact Incumbent network operations. Even though it would be possible to create an application without Incumbent interaction, this is not Ofcom's preferred approach.

It would also be challenging to account for any Incumbent deployment plans in the near future as, again understandably, this information would probably be confidential and not publicly available.

Though Ofcom will attempt to mediate compromise and monitor Incumbent objections to ensure they are consistent, reasonable, and justifiable, the work and engagement required to complete the application process will be time-consuming. Collecting correct and sufficient data, such as site surveys of spectrum usage or generating coverage and propagation models, to support a successful application will be a technical challenge and could require external input.

Once a successful application has been approved by Ofcom, with no objections raised by the Incumbent, engagement will need to continue to ensure continued co-existence between both parties, as dictated by both sets of licence agreements. This could involve modification of technical parameters, such as transmit power or synchronisation in time-division duplex (TDD) deployments.

Such potential changes, and the potential to accept those changes, should be reflected in any Local Access licensing application.

Finally, any extension of the licence beyond the initial agreed term would be subject to further discussion with the Incumbent, effectively a continuation or repeat of the application process.

While the default 3-year period could be sufficient to develop a business case or proposal, the Local Access licence does not guarantee the long-term deployment possibilities afforded by the Shared Access licence. This greatly limits its suitability for supporting the creation of viable business models.

4.3.4 Administrative Overhead

Another potential challenge for a prospective licence applicant is logistical and administrative effort associated with keeping records to the degree that Ofcom requires in order to support its wider spectrum management duties.

The requirements for basestations under low-power licences and mobile terminals in the 3.8-4.2 GHz band, under both licence types, should be relatively straight forward. This is because the recorded information on operating location for both situations requires only an address for the building or deployment site. However, any fixed terminals operating under a Shared Access licence, regardless of operating band or licence type, must have their locations recorded to a 1m resolution in National Grid Reference (NGR) format. It is unclear for how long this information has to be retained.

Some deployments of mobile technologies may also require a Mobile Network Code (MNC) to generate a Public Land Mobile Network (PLMN) ID. Private networks are advised by Ofcom to use the Mobile Country Code (MCC) *999,* which was made available by the ITU for internal network usage. This would not require any input from either Ofcom or the ITU. However, public networks, providing independent or supplementary coverage, will require an MNC or telephone numbering or both. This will involve further communication and registration with Ofcom, with further administration and licensing paperwork which could require external advice or input.

4.4 5GNT Tools to Simplify Access to Shared Spectrum Bands

As part of 5G New Thinking's efforts to create a toolkit to support rural 5G network deployments, tools for streamlining the LAL and SAL application processes were created[8]. Prototypes for full automation of SAL issuance were also created, managing SAL spectrum as

[8] The LAL and SAL tools can be accessed via the 5GNT Toolkit: (https://toolkit.5gnewthinking.org/index.php/Interactive).

a Dynamic Spectrum Access band, tools were developed for regulators to manage SAL spectrum licences.

4.4.1 Local Access Licence Tool

To receive a LAL, the rural operator must submit to Ofcom an application which:

- describes the plans for the network, including sites, frequencies, and transmitter details;
- documents when they're planning to commence operation of the network;
- presents reasons why the operator believes that the MNO is not currently using spectrum in the local area;
- shows why the operator believes that the planned network will not cause interference to existing MNO operations;
- provides contact information in support of the application process;
- provides, where applicable, evidence of any collaboration with the MNO.

Upon receipt of a LAL application, Ofcom will review the application for any obvious errors. If they find none, they will forward the application to the respective MNO(s) for the frequency band being applied for; otherwise, they will return the application for correction. The MNO(s) will review the application and may agree or object to the application, or reach out to the rural operator for more information. If an MNO objects to the application (e.g. for interference to existing or planned MNO operations), then the MNO will report this to Ofcom, who will, in turn, inform the LAL applicant.

The LAL tool steps the LAL applicant through this process, prompting the user for the necessary data, automatically generating the requisite coverage and interference analysis, and guiding the user through the necessary Ofcom and MNO interactions.

After prompting the user for some general information about the planned network, the tool then guides the user through selection of:

- desired coverage area (user selectable on a map as a polygon);
- desired frequency band to use;
- intended operating bandwidth.

The tool helps the applicant to identify which frequencies are not in use by MNOs in the desired area by depicting MNO usage in orange (both frequency and coverage), and where interference to existing MNO operations is clear from plans (e.g. where planned coverage overlaps with existing MNO coverage). Potential issues are flagged by turning guidance bars red; choices that appear acceptable are highlighted in green; choices remaining to be made are shown in grey.

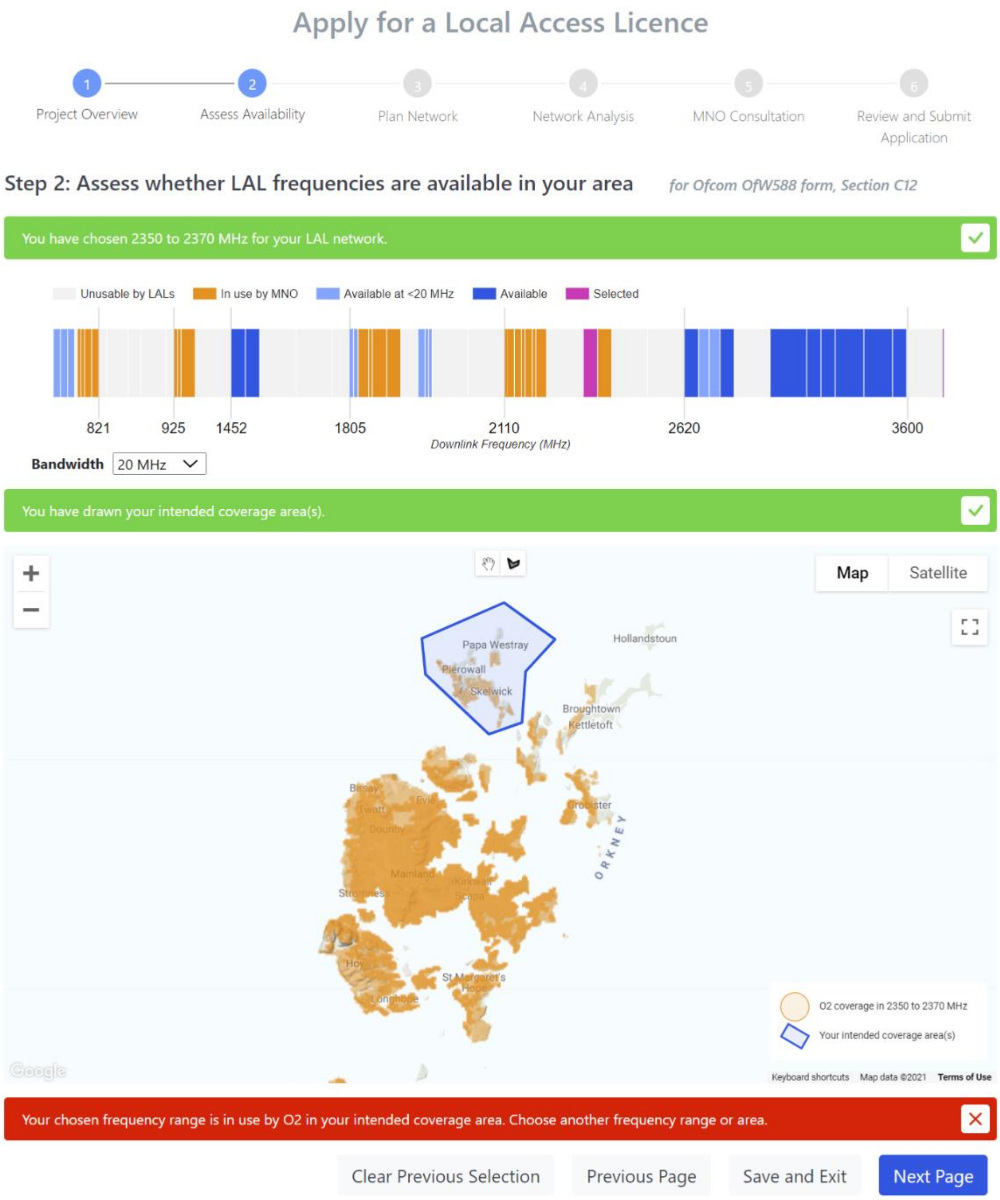


Figure 4.6: Selection of network area and desired frequency band.

In the next step, the applicant inputs the sites and transmitter characteristics for each site, including locations of the sites, the antenna(s) used with each site, and the transmit power that will be applied at each site.

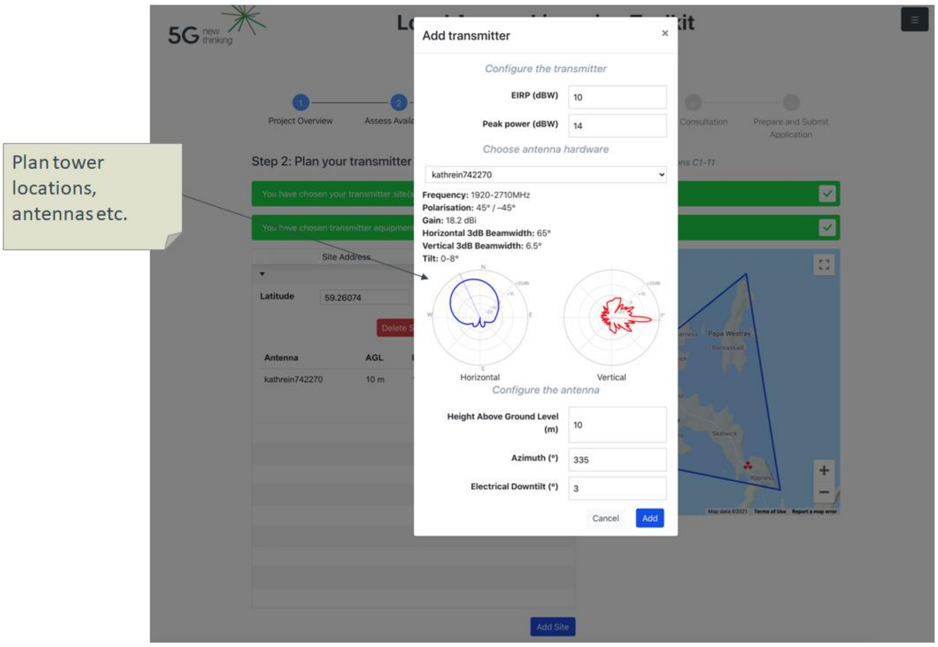


Figure 4.7: Site and antenna configuration.

The tool then performs RF analysis for coverage and interference to existing MNO operations. The analysis depicts areas with strong signal strength (suitable for indoor reception) in green, areas with weaker coverage (suitable for outdoor reception) in yellow, and areas where detectable signals are expected (and thus potential interference to existing operations) in red.

The tool flags if any interference to an MNO is expected and if the designed coverage area appears inefficient (relative to the desired coverage area) with messages displayed in red (problem) or green (expected to be okay). Because the tool is working with conservative assumptions, it allows applications to proceed even with identified potential problems.

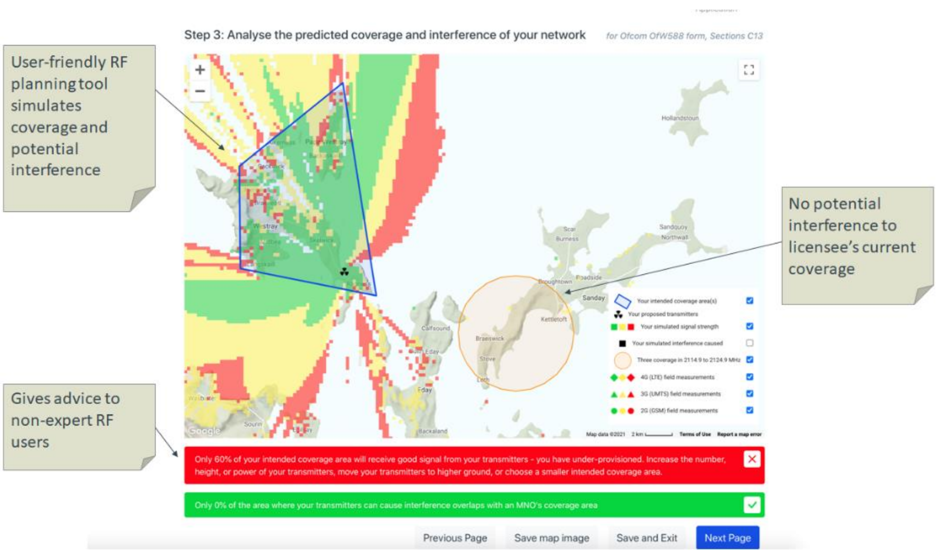


Figure 4.8: Estimate of coverage.

The tool then provides contact information for the MNO for the frequencies in use and provides a mechanism to capture any agreement made with the MNO that should be passed along to Ofcom as part of the application. The applicant can make use of the analysis from the preceding screens as part of their discussion, but that discussion has to occur outside of the toolkit.

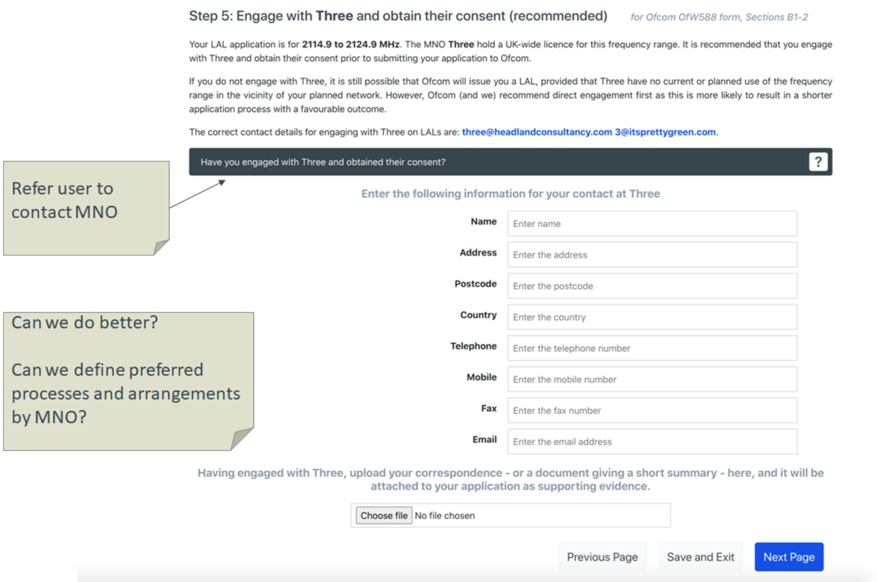


Figure 4.9: Form to capture MNO engagement.

Finally, the tool auto-fills the application and presents it to the applicant for review and prompts the user to submit it to Ofcom. The form can be edited offline, as needed, by downloading the PDF file and editing the fields.

If the user wishes to track the application within the tool, upon clicking submit, a GDPR form is presented, allowing the tool to be copied on correspondences with Ofcom. If the user chooses not to use the tool to track correspondences with Ofcom, then the form can be emailed direct to Ofcom by the applicant.

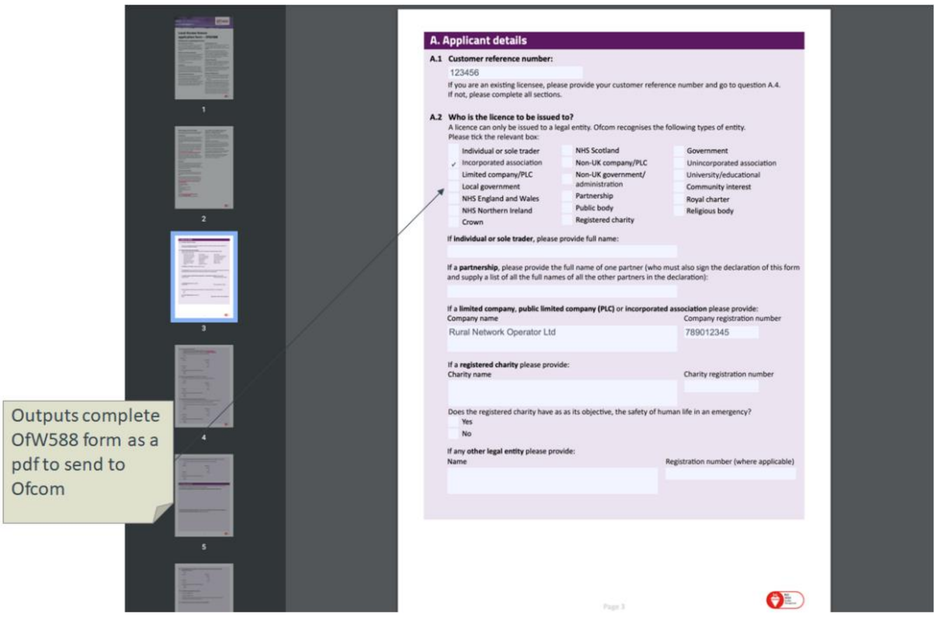


Figure 4.10: Form to capture MNO engagement.

4.4.2 Shared Access Licence Tool

A Shared Access Licence (SAL) is a one-year renewable licence. To receive a SAL, an applicant first submits a completed OfW589 form[9] to Ofcom to specify information about intended network operation (e.g. band, location, tower height, antenna gain). Ofcom first verifies that proposed operations comply with rules and limitations which include:

- **Fixed vs Mobile**
  - 3.8 GHz is only meant for fixed and private networks.
  - 1800 and 2300 MHz are not meant for fixed wireless access
- **Low-power vs Medium Power**
  - A low power licence (max EIRP 24 dBm) supports the operation of as many base stations as desired within a radius of 50 metres.
  - A medium-power licence (max EIRP 42 dBm) authorises a single base station and is generally only permitted in rural areas though Ofcom will consider urban area exceptions. Note that locations within UK's territorial seas, but not in an urban area, are treated as rural areas.
- **Indoor vs Outdoor**
  - Indoor operation causes less interference and is generally more permissible
  - 2300 MHz is initially only available widely for indoor low power licences
  - Lower 26 GHz is indoor low power only

[9] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0029/183746/OfW589-Shared-access-licence-application-form.pdf

Band	Bandwidth (MHz)	Operation Limits	Excluded Areas
1800 MHz	2x3.3 (FDD)	Mobile or private. Medium power antenna heights < 10 m	Isle of Man, Channel Islands
2300 MHz	10	Mobile or private. Initially indoor low power only.	Isle of Man, Northern Ireland
3.8 GHz	10-100	Fixed or private. Not intended for national mobile networks.	No use within 5 km of certain MoD sites
Lower 26 GHz	50, 100, 200	Fixed or private. Indoor low power	Not within 1 km of certain radio astronomy sites

Table 4.3: Summary of SAL Spectrum Availability.

Assuming the proposed operational constraints and network configuration limits (e.g. antenna gain, height, etc.) are satisfied, Ofcom then attempts to find a frequency assignment within the requested band that will not cause harmful interference to any protected system by following procedures which including the following at 3.8 GHz:

- Inter-service coordination (Fixed Links, Permanent Earth Stations, and UK Broadband) conform to specifications in OfW446[10] where:
  - Fixed links are expected to operate in 3815-3875 MHz paired with 4135-4195 MHz
  - UK Broadband deployments are within 3925-4009 MHz
- Existing SAL operations are protected at an I/N of -5 dB (low power) and -6 dB (medium power).
- Omni-directional antennas are assumed for coordination, but the nominal gain of the medium power site antenna (0-16 dBi) is included in link budgets along the receive path in all directions.
- TX and RX masks are applied for adjacent channel modelling.
- Indoor⇔outdoor attenuation is modelled at a fixed 12 dB.
- A channelization scheme is enforced with a minimum bandwidth of 10 MHz and overlapping channels for bandwidths 40 MHz or larger.

RAPID SAL

The SAL tool streamlines the SAL application process by replicating the published SAL coexistence calculations and online data sets as hosted in the Wireless Telegraphy Register (WTR) within an online tool called RAPID SAL. As illustrated in Figure 4.11, the RAPID SAL workflow first prompts you for location, then operational information, and finally planned licence duration before displaying the spectrum predicted to be available by Ofcom. For 5G private network operators, this has the following benefits:

- Availability can be assessed in in seconds instead of a month-long manual process with Ofcom.

[10] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/92204/ofw446.pdf

- The user is given immediate feedback and guidance on potential form errors (e.g. applying for a medium power license in an urban area) and allowable combinations (indoor / outdoor, band, bandwidth, power, antenna).
- An applicant can iterate on locations and configurations to improve a deployment prior to application.

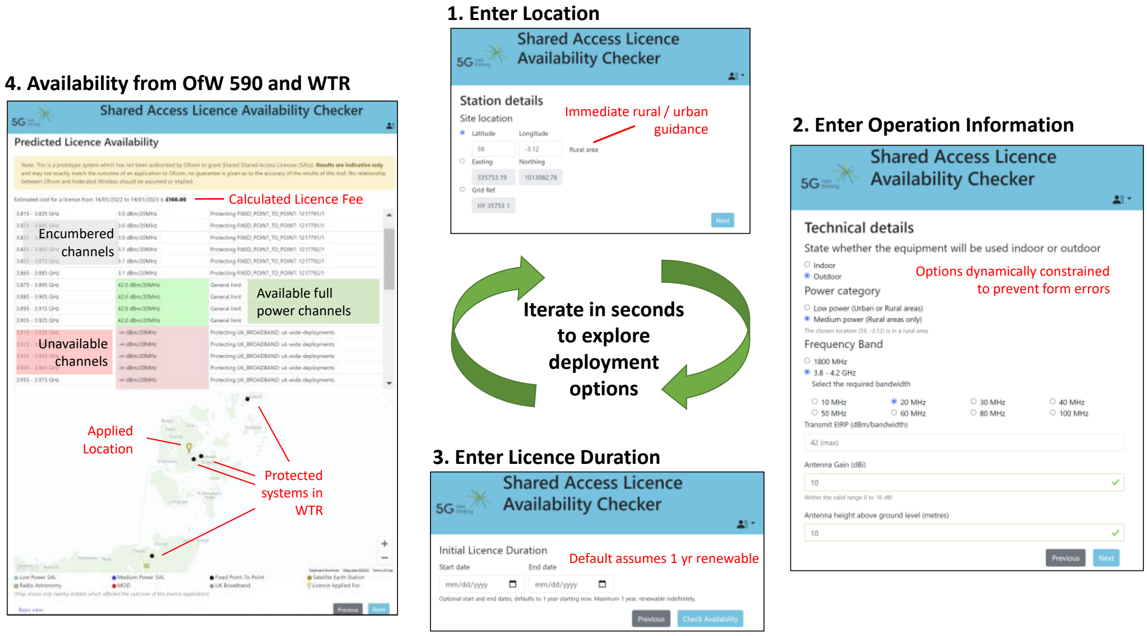


Figure 4.11: The RAPID SAL workflow enables SAL applicants to rapidly evaluate the spectrum available for their SAL private network. Hosted at: https://www.5gntsharedaccesslicencing.uk/.

Additionally, the RAPID SAL provides additional forward-looking prototyped capabilities to:

- Automate the process of applying and managing SALs.
- Enable full DSA operation in the SAL bands. The use of a REST-based protocol for spectrum client-server interactions supports DSA-to-the-device (or network) automation as well human-in-the-loop operation for legacy device support when conditions support longer heartbeat intervals (e.g. once a month is consistent with current conditions).
- Manage access constraints and methods dynamically by location, band, time, and user.

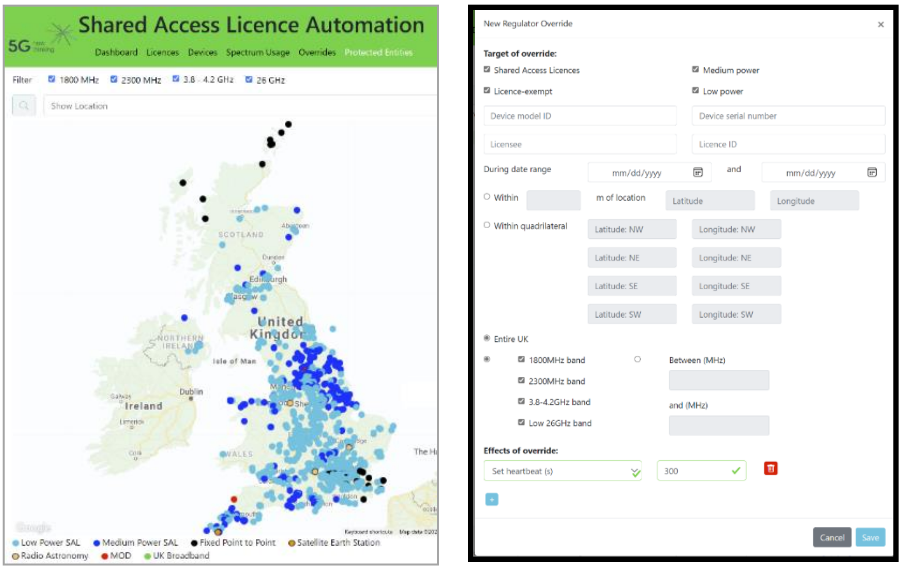


Figure 4.12: Data View (left) and Constraint Management View (right) available in the prototype Regulator Interface.

Additional Tool Capabilities

Figure 4.13 illustrates the different use cases supported by the SAL Automation Tool:

- **Existing Fully Manual** process wherein the SAL Automation Tool will pick up any Ofcom-approved SAL from Ofcom databases and apply the specified protections.
- **Augmented Manual** process wherein the SAL Automation Tool provides guidance on the feasibility of the application prior to submission.
- **Streamlined Manual** process wherein the SAL Automation Tool is used to complete and approve a SAL application, which would then be coordinated with Ofcom databases via a to-be-decided (TBD) process.
- **Automated-to-the-Engineer (ATTE)** process wherein the SAL Automation Tool performs the streamlined manual process and then regularly verifies continued operation via web interactions with the engineer responsible for the SAL devices.
- **Automated to the Device (ATTD)** process wherein the SAL Automation Tool works within SAL protection calculations and implements full DSA (database enabled) to an individual radio.
- **Automated to the Network (ATTN)** process which is the ATTD process to multiple devices is mediated through a domain proxy / network manager with one or more SALs.

Additionally, the SAL Automation tool provides tools for an Ofcom engineer to interface with the tool to review status, tune regulations, and manage devices.

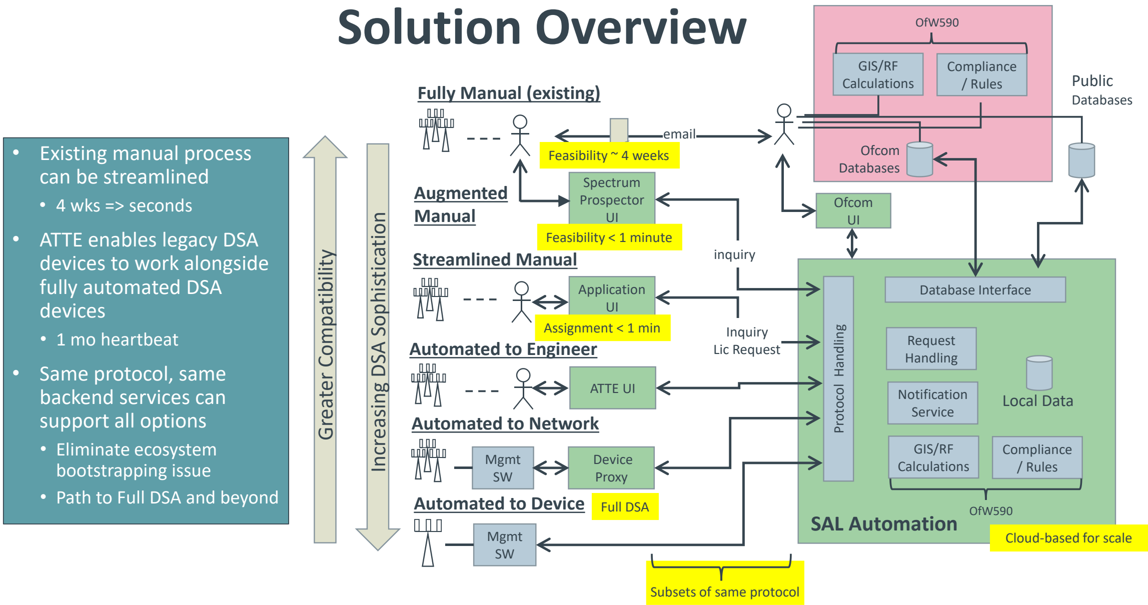


Figure 4.13: Use Cases Supported by the SAL Service Automation.

4.4.3 Protocol/APIs for M2M Access to the SAL Tool

The protocol and APIs for accessing the SAL tool can be used as part of various companies' efforts to automate their SAL applications, or as part of a standard for DSA server-client communications in SAL bands, or elsewhere due to its generalizability.

4.5 Using the LAL Tool In Practice

The 5GNT Bogons-led LAL application was generated using the LAL tool. A brief overview of the parameters of that application follow. The licence was granted by Ofcom on March 31, 2022.

Table 4.4: Bogons Balquihidder LAL Application Details:

Feature	Value
Location	Balquhidder
Size of Network (Area)	26 km^2
Type of Network	Mobile, Outdoor
Number of Transmitters	3
Bands	758-768 MHz, 1805.1-1810.9 MHz
MNO	O2
MNO Engaged Prior to Submission?	No
Estimated Area of Interference	22.0 km (outside area; 1805 MHz)
Proposed Duration of Operation	3 years (max)
Time to Complete Application (in Tool)	1 day
Time to Complete Application (in Total)	3 weeks

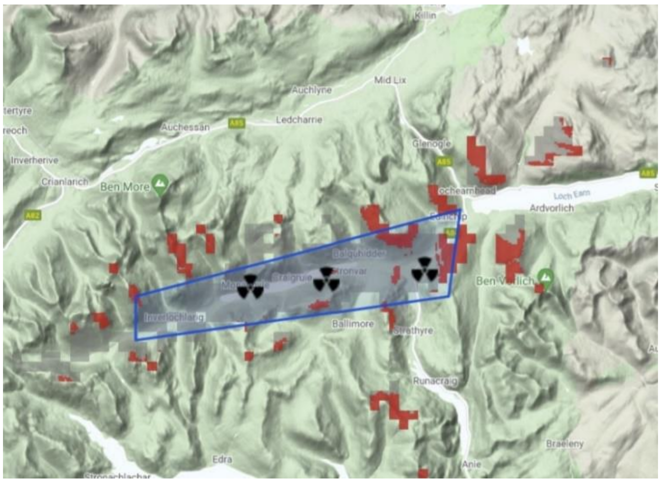


Figure 4.14: Auto-generated Interference Analysis for 1805 MHz.

Supporting this effort led to key areas of the tool being identified for improvement as described in Table 4.5, which also describes how the application was impacted, and how the issue was resolved – either addressed now or deferred for future resolution.

Table 4.5: Identified Areas of Improvement to the LAL Tool from the Balquidder

Area	Application Impact	Resolution
Edit Application in Word	Upon viewing the application, there were a number of items where wording edits might want to be revisited without going through the tool. Because of inconsistencies in pdf form rendering across viewers, this proved difficult even when collaborating internally	Deferred. Should coordinate with Ofcom on a Word version of the application
Support for new bands	The toolkit only supported the original bands, but the 750 band was desired for better coverage even though 3 years since auction had not passed.	Coordinated with Ofcom on acceptability of applying in these bands (may not be approved). Additional band support added to tool
Antenna pattern updating	Was not clear how to upload new antenna patterns planned for this application.	Dev team directly updated available antennas
Multiple band support	A dual-band network was desired. Applying for both bands as two separate applications would double costs.	Informed Ofcom of desire for multi-band. Deferred updating the tool, but combined the pdfs into a single application.
Bug in service class code	The tool was populating the wrong service class code.	Fixed
Support alternate bandwidth	Older bands (2G) have different bandwidths than 4G / 5G, but are available for use and were desired for use. The tool was assuming the same bandwidths would be used.	Tool updated to support bandwidths other than the original channelization.
Bug in site location quantization	GPS quantization of the sites was causing the sites to move upon exiting and re-entering the tool leading to unexpected changes in coverage and interference.	Fixed
Moving sites by mouse	When exploring site locations, it would quicker / easier to be able to click on the map for the site location and drag around sites rather than entering locations by hand.	Deferred

Area	Application Impact	Resolution
Labeling	Minor labelling issues (transmitter IDs) and wording around	Fixed
Bugs	Appendix results were confusing / misleading	
Power labels	Application requests effective radiated power a few different and redundant ways, which led to questions on how they were being used due to the redundancy.	Deferred. Currently part of the form itself. Could be reworked

4.6 Using the SAL Tool In Practice

Instead of waiting a month for an Ofcom response, SAL applicants can now learn in seconds of problems that would cause rejection, such as applying for medium power licence in an urban area or using disallowed antenna heights or gains, and furthermore learn the available frequencies for their application and of 3rd party systems that may need coordination.

This makes SALs more attractive for events and simplifies usage for new (and existing) private 5G network operators. Indeed, automation, streamlining, and "softwareisation" of the SAL process has been recommended by DCMS and Tech UK[11] and identified as an Ofcom strategic goal.[12] Though the tool just exited Beta (invitation-only) in February 2022, the SAL Spectrum Inquiry Tool is available as freemium software for which 23 commercial users have signed up.

More formally, the SAL Tool was made available to Beta Testers and feedback was collected from several external organizations.[13] Demonstrations were also made to the MoD and Ofcom. From demonstrations and meetings, Ofcom:

- was impressed with the speed of response, both for the overall calculation of availability and the determination of rural vs urban from the GIS lookup;
- saw significant value in the potential to reduce uncertainty and errors in applications;
- was concerned that any discrepancies between the public tool and what they returned could create political headaches;
- noted that some data is not in the Wireless Telegraphy Register (WTR) – sensitive Ministry of Defence (MoD) sites, UK Broadband, pending approvals;
- noted that there are errors in the database;
- noted that our disclaimers are sufficient to avoid confusion.

Other users noted the value of the quick feedback on rural vs urban distinction (a common issue for applications. One noted that they used the tool to resolve an unhelpful rejection from Ofcom where they used the tool to show Ofcom that it was their own system that they would be interfering with and were then granted access and had since used the tool on hundreds of applications. At the 5G Showcase, two other companies noted that the tool would allow them to more quickly iterate on alternate sites and would make it easier to proceed with network planning instead of having to wait for approval and were going to include the tool in their normal SAL application process.

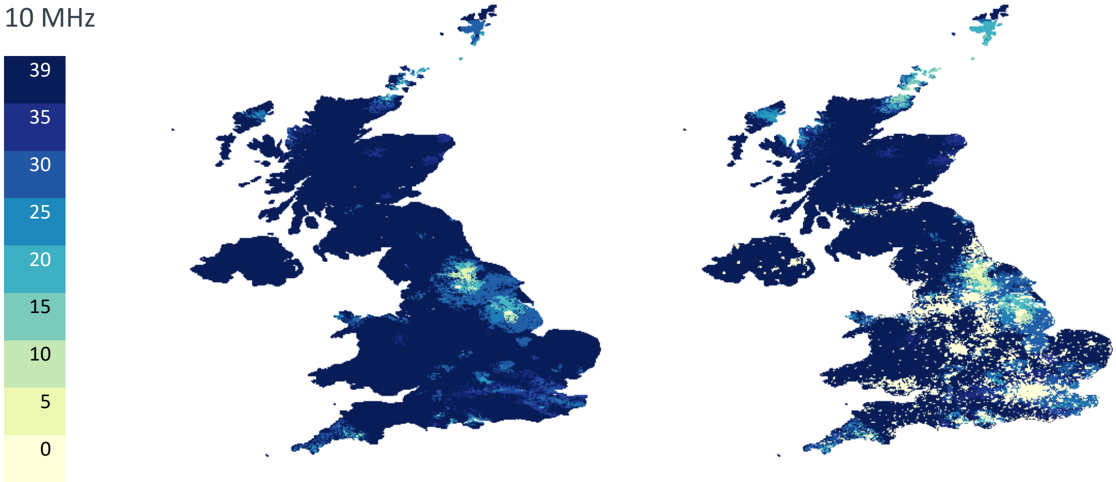
[11] See: https://www.techuk.org/asset/26E1BD00-A2F7-4FF8-B717FF0BF9AB4E81
[12] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/222173/spectrum-strategy-statement.pdf
[13] Identifying information has been removed for privacy considerations.

4.6.1 White Paper

Using the SAL tool, a white paper[14] was created, analysing current access availability to SAL n77 spectrum (3.8-4.2 GHz) and the impact of alternative regulatory considerations on SAL spectrum access and capacity, with example results shown in the following tables.

Table 4.6: Current SAL Availability in the UK Ignoring UK Broadband

# Chans	Low Power SAL	Medium Power SAL
10 MHz		



Low Power SAL

	0 channels	1 channel	2+ channels
Area	0.08%	<0.01%	99.9%
Pop	0.01%	0.05%	99.9%

Medium Power SAL

	0 channels	1 channel	2+ channels
Area	12.3%	<0.01%	87.7%
Pop	77.5%	<0.01%	22.5%

Table 4.7: Comparison of SAL Spectrum Availability by Policy for 100 MHz Channels

Policy Summary #Channels	Area			Population Weighted		
	0	1	2+	0	1	2+
Existing Low Power	1.90%	11.10%	87.00%	1.00%	20.30%	78.70%
No UK Broadband. Low Power	0.50%	1.80%	97.60%	0.40%	1.30%	98.40%
Low Power SAL with Higher Fidelity Antenna Models	0.88%	6.30%	92.90%	0.30%	5.10%	94.60%
Existing Medium Power	16.20%	12.60%	71.10%	78.30%	5.30%	16.40%
No UK Broadband. Medium Power	13.10%	3.30%	83.60%	77.70%	0.85%	21.40%
Medium Power, 5 dB Less Interference Tolerance	16.50%	13.00%	70.50%	78.50%	5.40%	16.10%
Medium Power, 5 dB More Interference Tolerance	16.20%	12.30%	71.60%	78.20%	5.30%	16.60%

[14] https://toolkit.5gnewthinking.org/SAL_whitepaper.pdf

Policy Summary	#Channels	Area			Population Weighted		
		0	1	2+	0	1	2+
Decreased Medium Power EIRP		14.60%	10.30%	75.10%	78.10%	4.30%	17.60%
Decreased Medium Power EIRP, No Protection		13.20%	7.40%	79.30%	77.60%	2.90%	19.50%
Medium Power with Higher Fidelity Antenna Models		14.20%	9.00%	76.90%	77.70%	3.50%	18.80%

Table 4.8: Estimates of UK-Wide SAL Relative Capacity Under Different Scenarios

Protection				Results	
Protects PES + MOD + Fixed P2P	Protects other SALs	Protects UKB everywhere	Scenario	Low Power Capacity	Medium Power Capacity
✗	✗	✗	Empty UK Baseline	100%	87.8%
✓	✗	✗	-	99.0%	85.7%
✓	✓	✗	-	95.3%	81.2%
✓	✓	✓	Current	61.7%	51.6%
✓	✓	✓	Horizontal antenna directivity	64.0%	54.2%
✓	✓	✓	SALs 5dB more tolerance		51.4%
✓	✓	✓	SALs 5dB less tolerance		51.8%
✓	✓	✓	@24dBm EIRP		53.5%
✓	✓	✓	@24dBm EIRP, no reciprocal protection		55.4%

The following are some of the impacts seen from policy variations, anticipating a future, more densely deployed SAL market

- The largest realized gains for alternate policies are seen in the scenarios where spectrum is currently least available, which is as expected in general and from the specifics by which availability is calculated in this whitepaper.
- Improving antenna modelling fidelity in medium power SAL interference calculations is seen as a largely "free" technique to increase medium power SAL

access (ability to add one or two sites at a location) by up to 20%[15] and low power SAL access by 45% without impacting SAL network operations or interference protections. Likewise, overall capacity for medium power SAL deployments would be nearly doubled in this scenario.

- Larger access gains (29%) could be achieved by reducing medium power SAL EIRP and eliminating interference protections for new applicants from incumbent operations, though this would have negative operational impacts.
- Surprisingly, adjusting interference tolerance for medium power SALs had little impact on spectrum access availability, which may be a result of protection of existing medium power SALs not being a strongly limiting factor to access outside of Sheffield/Leeds where the density of Quickline deployments dominates any effects the mechanism may have.

[15] At 100 MHz, medium power SALs access to 2+ non-overlapping channels increase from 71.1% to 76.9% recovering 5.5%/28.9% = 20% of access opportunities.

5 5GNT Workshop Events

During the project, three workshop events were organized and run by 5GNT project partners. It was originally envisaged that these would be face-to-face events, but due to Covid restrictions in place throughout most of the project, they ended up becoming on-line events instead.

5.1 Workshop 1: A Journey for Rural Communities

The 5G New Thinking Project (5GNT) held its first Workshop on 11th November 2020 via the Webex meeting platform. There were 22 attendees of the event including community groups, rural organisations and local authorities. Delegates were welcomed to the event by Cisco and Orkney Islands Council. As part of this welcome, delegates were invited to complete an online survey about their organisation, interest in 5GNT and the issues that they are seeking to solve.

Cisco gave the first presentation of the workshop, giving insight into Cisco's role in supporting the development of 5G and communications innovation.

The University of Strathclyde gave an overview of the 5GNT project. This presentation introduced the 5GNT consortium members and gave an overview of the project's key aims, including the primary aim of developing a 5G community network deployment toolkit.

The next presentation, on Mobile Services, was provided by Cisco. This gave an overview of the current mobile coverage and limitations on the Orkney Islands as well as explaining in simple terms the definitions for good mobile coverage. The presentation went on to discuss the models of traditional international roaming and the neutral host approach which is increasingly proposed as a way of supporting access to mobile services with less investment from major mobile operators in infrastructure. An overview of the 5G Rural First project model was presented and the options for building on this work through neutral host and multi-sim SIM models was discussed.

Orkney Islands Council gave a presentation about the islands and the importance of proactively seeking to encourage development of improved digital connectivity. The presentation reviewed the 5G Rural First project and a number of the use cases that were developed in Orkney to test the use of 5G technology. It was noted that mobile operators are not using all of their licensed spectrum in Orkney and therefore that there was potential through sharing this spectrum to develop improved connectivity across the islands. The presentation closed with an overview of the next steps and the works to be done through 5GNT.

After a short break, The Borderlands Partnership gave an overview of the Borderlands region, the aims of the Borderlands Partnership, and the Partnership's interest in improving digital connectivity and the reasons for supporting 5GNT.

The Rural Community Network Northern Ireland then gave a presentation outlining the background and aims of the Rural Community Network including its key areas of work in governance support, peacebuilding, policy responses, membership meetings, and dissemination of good community development practice and research. The presentation provided a high-level overview of the Northern Ireland local authority framework and compared it to other parts of the UK, noting that the Rural Needs Act (NI) 2016 provides a statutory duty on public authorities to have due regard to rural needs when developing, adopting, implementing, or revising policies, strategies, and plans, and when designing and delivering public services. It went on to discuss the dual impact of Covid 19 and Brexit on Northern Irish rural communities, which has further highlighted the need for comprehensive digital connectivity. The presentation closed with an overview of digital infrastructure developments in Northern Ireland and the Rural Community Network's aims in supporting 5GNT.

The final presentation of the workshop was given by Pure Leapfrog on Commercial Aspects. This comprised an overview of Pure Leapfrog's aims to ensure that disadvantaged or vulnerable communities do not miss on out the social & environmental benefits of carbon reductions in the systems/infrastructure of everyday life including energy, transport, housing, and digital connectivity. The floor was then opened for discussion and questions.

5.2 Workshop 2: Funding and Finance

5GNT held its second Workshop on 25th February 2021 via the Webex meeting platform. There were 48 attendees, representing community groups, rural organisations, government agency representatives, and local authorities. Delegates were welcomed to the event by Cisco.

Pure Leapfrog gave the first presentation of the workshop, providing an overview of the project and an update on progress to date.

To set the scene for the workshop, the University of Strathclyde gave a presentation on the key costs to consider when planning to build and operate a community network. This included both capital and operating costs as well as potential income streams.

Pure Leapfrog then gave a presentation on community finance options together with the funding requirements at different project stages and the associated risks of each phase: development/business planning stage; deployment/construction phase, and operation phase.

After a short break, representatives from three external organisations gave very valuable and diverse presentations.

First, Big Society Capital gave an overview of social investment and finance. This explained what social investment is, how it can be accessed, and the types of funder in the market. The presentation went on to discuss the different sorts of social investment available to projects and their applications.

Next, the Plunkett Foundation gave an overview of different community business models (Community Benefit Societies, Community Interest Companies, etc) and their key features. The presentation then explained their most appropriate applications considering their funding, legal and governance constraints.

The final presentation of the workshop was given by Rose Regeneration on social impact and the importance of quantifying the social value of community projects. The presenter then discussed how social impact measurements can be applied, the different methodologies available, and their limitations.

5.3 Workshop 3: Mobile Network Operations

5GNT held its third Workshop on 17th June 2021 via the WebEx meeting platform. There were 53 attendees, representing community groups, rural organisations, government agency representatives, and local authorities. Delegates were welcomed to the event by Cisco.

Cisco then set the scene for the workshop and provided a non-technical explanation of the barriers to achieving full mobile coverage in the UK – this included regulation, access to spectrum, and the current poor business case for delivering services in rural areas. The presentation went on to provide details of alternative options being considered to aid communities in developing and building their own solutions.

Orkney Islands Council gave a brief presentation on mobile coverage in Orkney, using maps provided by the mobile operators to Ofcom to indicate their anticipated coverage in Orkney. Those maps were then compared against actual on-the-ground readings using SIM cards to measure signal strengths during a drive around all of the main roads on Mainland Orkney. This showed the disparity between expected coverage and actual coverage.

Federated Wireless gave a presentation on spectrum. This included an explanation of why spectrum is needed to deliver mobile services, how it was made available to mobile operators through an auction process, and changes to the system to allow the sharing of spectrum currently being trialled. The presentation also detailed how the cost and conditions surrounding accessing spectrum and licences, including ongoing charges, make it uneconomic to deliver to rural areas. It finished by outlining the work that Federated Wireless is undertaking through the development of software to assist rural communities and the regulator with spectrum licence applications.

Virgin Media (VM) (formerly O2/Telephonica) gave a presentation from the industry perspective, providing details of VM's current network coverage and investment plans for the future. The presenter talked about VM's leading role in promoting the Shared Rural Network project – funded jointly by industry and the UK Government – and of VM's commitment to the 5G New Thinking project's trials of neutral hosting in Orkney.

For the second session of the workshop, five valuable and diverse presentations on real-life examples of building and operating mobile networks in not spot areas were given.

First, Faroese Telecom gave an overview of the operation of mobile telecoms in the Faroe Islands. The presentation provided a brief history of the evolution of telecoms in the Faroe Islands, from when the state-owned company was first set up to the evolution of a 5G network. The presenter stated the company's continued commitment to developing services in both Orkney and Shetland should market conditions permit.

Next, Wavemobile provided a presentation on how to build mobile networks in the UK with an emphasis on local solutions for covering current not spots. The presenter provided detail of the building of a small network at a busy railway station which, at the time, had no 3G or 4G services. He considered what the basic requirement of the average customer was. Details on how they built such a network using the principles of lowest cost and limited range to cover just the not spot were also described. Finally, the presentation provided details of plans to upgrade the network for the future, using 5G.

Telet Research gave a presentation on delivering neutral hosting in the Chalke Valley, explaining how neutral hosting operates, the business case for operating such a service in any area, and Telet's plans to expand coverage in the future. The presentation also commented on the 'real life' pros and cons of small network development and the challenges faced.

Bogons gave a presentation on the Balquidder experience – from building a broadband network to plans for trialing a mobile network using 5G. This provided an insight into the role of the community in developing and driving forward network builds, and the risks associated with cost recovery.

The final presentation of the workshop was given by the MANY project on the business case for mobile networks. This provided a practical step-by-step guide on how to develop and build local networks, possible business models, and key revenue and capital drivers to ensure viability.

There followed a lively debate from the panel members from the questions raised from the audience. They centred on the topic of spectrum licences, especially on how difficult they are to get.

The panel members gave their views on the roles of the community and the need for strong local community buy-in to improve the chance of successfully delivering local network solutions. They also provided advice on what communities can do themselves and when to call in professional services to support and guide them.

In their concluding remarks, Cisco and Orkney Islands Council gave an overview of the next steps for the 5GNT project, including the development of a 'toolkit' to aid communities wishing to build local networks. All of the delegates and speakers were thanked for helping to make the event a success.

6 MNO Engagement

5G New Thinking engaged with MNOs over two key pillars:

1. 5GNT and its partners reached out to several mobile operators in the initial stages of the project, through partner contacts or collaborating partner contacts, to engage them in requests for ongoing participation in the project.
2. Research was conducted by Coleman Parks Research on behalf of 5GNT, with the goal of understanding the appetite among MNOs for using Neutral Host technology to help with alleviating the digital divide.

6.1 Pillar 1: Engagement with MNOs

All 5GNT dialogue with MNOs was on the topic of 'new thinking' for connecting remote rural communities to mobile operator networks, and most, if not all, of the dialogue was focused on providing localised coverage for the customers of those mobile operators.

Meetings occurred with the four mainstream UK operators: EE, Vodafone, Three, and O2, covering topics such as:

- **Local Access Licences (LALs)**
  All four operators were engaged on the topic of obtaining Local Access Licences, in a collaborative workshop led by the MONeH project. From 5GNT's perspective, there appeared to be a disconnect between the MNOs' expectations regarding engagement in the LAL application process and the regulator's expectations and its written procedures. More specifically, whereas Ofcom advises LAL applicants to engage with MNOs prior to submitting an application in order to gain insight into which parts of the spectrum are more likely to be available and attainable, the MNOs expressed a preference for applicants to submit their applications to Ofcom in the first instance, without prior discussion or engagement with MNOs, for reasons of time and resource constraints.
- **Technical Architecture for Mobile Coverage**
  Key issues from a technology perspective were:
  - What mobile generation do most radios support?
  - What capabilities reside in users' handsets over time. (e.g. VoLTE)?
  - What capabilities reside in operators' networks over time (including 'heavy' MVNO's)?
  - What mobile services must be supported (e.g. voice, data, messaging)?
  - What level of integration is necessary (from both the MNO perspective and the NH perspective)?
  - What are the relative costs (one-off and ongoing) (from both the MNO perspective and the NH perspective)?
  - What are the user needs?
  - What would be the minimum user experience requirements?

- **Processes and Procedures**
  - Understanding regulatory hurdles;
  - Understanding legal aspects;
  - Defining security policies and processes, and understanding the expectations of both the MNO and the HH provider;
  - Understanding the commercial opportunity and potential operating models.
- **Operational Aspects**
  - Customer experience requirements;
  - SLAs;
  - KPIs;
  - Customer care interfaces;
  - Security.

6.2 Pillar 2: Research and Insights Report

In 2020, 5GNT conducted a survey of senior MNO executives. The research showed that MNOs are keen to roll out 5G in rural locations but there is some resistance towards working with rural neutral hosting providers. This resistance is mostly to do with a lack of faith in their ability to play fairly in the market. As a result, MNOs want to work closely with rural neutral hosting providers, be part of the infrastructure location selection, have the same SLA as their competitors, and get clarity on how they can avoid losing their customers to the competition).

Further details of the survey and the results can be found in the report.[16]

[16] https://static1.squarespace.com/static/5f86c7ffc1c78201b817eb23/t/5f9ff2d30991472cc5475514/1604317907989/5GNT+Report_v5%281%29.pdf

7 Network Business Operations

Every community is different, and so too are its connectivity needs. When developing an appropriate solution for your community's connectivity needs, you need to think about the features that are unique to your community. Population density, topography, existing connectivity arrangements and network resources, and socio-economic factors will all play a role in determining the approach and business model that is best suited to your community.

A key feature of projects where communities have developed their own connectivity networks is the presence of a group of committed people who drive the project forward. In common with many community projects, this group is usually formed of volunteers, particularly in the early phases of development. At a very early stage, you will need to consider the resources that your community has available and whether there will be sufficient support to drive a project forward. This will impact the level and types of consultancy support and advice you will need for your project. To begin with, you could form a steering group with a core group of community members. As your project develops, you will probably need to form an incorporated entity, such as a Community Interest Company or Community Benefit Society, which has a board of directors offering a good mix of relevant skills and experience. In some communities, it may be relevant and appropriate to use existing community groups or structures as a starting point. These may be groups that are already formally constituted and have a board of directors from the community.

Ultimately, you are going to be running a business regardless of how you set up your community enterprise and how you resource it. And the usual rules of business apply, including the need to be commercially viable. However, depending on how you choose to run the enterprise and the legal structure that you choose for it, your priorities and aspirations, and the associated measures of success, might be different from those of a traditional corporate organization. For example, you might decide to prioritize social value over financial gain, and this would be reflected in the strategic decisions and choices made at each stage of set-up and ongoing development of the business.

With all of this in mind, you'll need to consider the following factors:

- **Create Your Business Plan**
  You will need to identify your community's needs and the applications and use cases that the network will need to support. As well as this, you will be working out business models and the associated cost-revenue analyses and setting up the community enterprise organisation that will secure the funding and finance you will need to build and operate your network and keep the business running into the future.

- **Plan and Build Your Network**
  Your network may include optical fibre runs, radio access networks, point-to-point microwave links, masts and electrical power facilities, all of which needs to be planned and designed. You will also need to consider coverage and capacity requirements, end-user devices, access to radio spectrum, access to mast sites and associated planning consent, network security, and more besides.

- **Operate Your Network and 'Run Your Business'**
  Once you've got the business plan defined and the network built, the next stage is operating the network and running the business.

7.1 Creating Your Business Plan

Every business needs a business plan. This not only helps you to clarify and define what the business will do and how it will be run, it also helps you to explain your business to other people, which is likely to be crucial if you are going to be seeking finance from outside investors.

In order to create the business plan, a number of factors need to be considered and addressed, and several iterations may be required as things take shape and become clearer:

1) **Market Analysis**
   a) What 'problem' are we seeking to solve?
   b) How big is the potential market? How will it change over time?
   c) Competitors – now? in the future?
   d) What do our customers need? Want?
   e) Where are our customers?
   f) What share of the market are we seeking?
2) **Business Model**
   a) Services to be delivered – to whom, when, service characteristics, bundling etc?
   b) Delivery model – how will it be delivered? What is the support associated with the service & how will it be delivered?
   c) Pricing model – how will services be priced
3) **Organization Structure**
   a) What format of organization will deliver the services? Will it be one or multiple?
   b) What relationships are required to make it work? Suppliers? Partners?
   c) Governance – how will it be governed? Board, Advisory Groups, Policies?
4) **Resourcing & Processes**
   a) What skills and resources are required for the business?
   b) Where will they be located?
   c) What resources (systems etc) will they need to function
   d) What systems and processes will guide & serve the organisation?
5) **Financial Analysis** – if there is no track record, this will need to be based on forecasts built on very robust assumptions (and in all likelihood a scenario analysis providing best case, worst case, base case)

a) Income statement

b) Balance Sheet

c) Cashflow statement

6) **Social Impact**
If you intend to seek funding from impact investors, you will need to have developed an impact framework, indicators, metrics and baseline data at a minimum in order to build your case.

7) **Risk Management**
You will need to have assessed the risks your business may face across multiple dimensions – including the likelihood and impact of each risk as well as the mitigating actions to be taken to address the risk and who is responsible for taking the mitigating actions.

Most of the above factors are common to any business regardless of whether or not it is to be run as a traditional company or as a community enterprise. However, the organization structure – in particular, the legal structure – is a critical decision that will influence many, if not most, other aspects of the business, including its strategy, its governance, and potential sources of funding and finance.

7.2 Legal Structure

While it is entirely possible that a traditional limited company could be set up locally to provide digital connectivity to customers, **Community Enterprise** structures can have certain advantages which may contribute to improving the overall business case in rural settings. These include:

1) The potential to access certain sources of funding and finance that would not be available for traditional business entities;

2) Increased community 'good will', which may lead to reduced costs and/or may make access to local land and infrastructure easier.

Depending on the circumstances, it may be helpful for a community organisation to employ the '**social enterprise**' or '**community enterprise**' label. While these are not legal definitions, there is some accepted usage of these labels, as described below:

- A **social enterprise** is a business with primarily social objectives, whose surpluses are principally reinvested for that purpose in the business or in the community. Rather than being driven by the need to maximise profit for shareholders and owners it instead seeks to reinvest any surpluses in the organisation or in the community to enable it to deliver on its social objectives. N.B. It is a common misconception that a social enterprise cannot make or distribute a surplus.

- A **community enterprise** is an organisation, normally with a social purpose, which is set up, owned, and controlled by a geographical community or a community of interest.

There is no single legal structure for social enterprises. It is not its legal structure that determines whether an organisation is a social venture, it is its activities.

In the UK, there are two dominant types of community legal structures that have specific governance structures: a **Community Benefit Society (BenCom)** and a **Community Interest Company (CIC)**. Table 7.1 lists some key features of BenComs and CICs.

Table 7.1: Key features of BenComs and CICs.

	BenCom	CIC
Main focus	A community-focused, non-profit organisation	A social enterprise with a protected social mission
Social Purpose	Benefit of the Community	Benefit of the Community
Changes to Purpose	FCA must approve any changes	The Regulator will only approve a change if it meets the community interest test
Asset lock	Yes (loopholes exist)	Yes
Constitutional document	Rules	Articles of incorporation
Ability to raise share capital	Yes	Yes, if limited by shares
Regulator/Registrar	Financial Conduct Authority (FCA)	Companies House & CIC Regulator

The issues to consider when selecting a legal structure for a social enterprise include:

- Governance;
- Ownership;
- Personal liability;
- Profit distribution;
- Financing sources.

7.2.1 Governance

Governance comprises the systems and processes concerned with providing the strategic direction, oversight and accountability within an organisation.

In CICs and BenComs, the governance function is undertaken by a Board of Directors or a Management Committee, depending upon the legal structure of the organisation. The governance function should not be confused with the management of the organisation's day-to-day operations, undertaken by executives.

The relationship between the members and the governing body is defined in the governing document, which contains information about all the practical matters related to how an organisation is run, including:

- Its aims or objects and how they will be achieved.
- Who the members are, how they can become members and how they meet and make decisions.
- Whether there is a governing body, what is it called, how it is appointed and how it meets and makes decisions.
- What happens to any profit/surplus.
- What happens to assets when the organisation is sold, taken over or broken up.

7.2.2 Ownership

In a CIC limited by shares, members have a shared ownership of the company.

A CIC limited by guarantee does not, by definition, have shares. The company has a number of guarantors. If each member guarantees the same amount, they will usually have one vote each. This gives a much more balanced voting structure, which explains why this legal structure is used by the majority of social ventures in the UK. Companies limited by guarantee are free to distribute their profits to members in the form of dividends. However, in case of CIC's those dividends are capped.

In a BenCom, each member will usually have one vote, regardless of how much they invest.

7.2.3 Personal Liability

Generally, most social ventures that intend to operate longer-term will seek to use a legal structure that offers the owners / guarantors / members limited liability.

This is what makes incorporated legal structures, such as CICs and BenComs particularly suitable in this case. These structures separate the members/owners from the enterprise and will limit their personal liability if the venture suffers financial loss; or if financial loss is caused by the enterprise.

There are differences in the limits to the personal liability of a member in the event that the organisation is wound up and is unable to pay its creditors, depending on the legal structure:

- In a CIC limited by guarantee, the personal liability of the member is limited to a fixed amount, typically £1.00.
- In a CIC limited by shares or a BenCom, the liability is limited to the value of the paid up shares held by the member.

It is important to note that members/directors cannot benefit from limited liability in all circumstances, for instance when they are proven to have acted negligently or fraudulently. In those cases, it is possible that they will be personally liable.

Directors will also be liable for enterprise's debts for which they have signed a personal guarantee, which may be required by some lenders where there the enterprise is unable to provide sufficient security.

7.2.4 Profit Distribution

Profit-making may not seem to be a priority for a social-impact focused community 5G enterprise. However, its business model must ensure it is generating sufficient levels of income to deliver its purpose, raise finance and keep it financially sustainable. How the profits generated by a community 5G enterprise are used is determined by its legal structure and financial strategy.

CICs limited by guarantee tend to reinvest the profits in the company rather than distribute them to the guarantors. The idea is that the company will use the profits to grow the enterprise and increase its social impact.

A CIC limited by shares, which adopts the appropriate clauses in its articles, and subject to company law requirements, may pay a dividend on shares if agreed by a resolution of its members.

A CIC limited by shares under Schedule 2 of the Companies (Audit, Exemption and Community Enterprise) Act 2004 is a "not for profit" company as it cannot distribute profits to members that are not an asset-locked body, such as, a charity.

A CIC limited by shares under Schedule 3 of the Companies (Audit, Exemption and Community Enterprise) Act 2004 can aim to make profit and that profit can (under certain checks and balances) be distributed to its members (who may or may not form part of the requisite community) in the form of a dividend, but it may not necessarily do so. Dividends payable to certain types of shareholders (non-asset locked bodies e.g. not a charity or C.I.C.) will be subject to a dividend cap. The cap is, at present, a maximum dividend per share of 5% above the Bank of England base rate and a maximum aggregated dividend of 35% of the distributable profits.

This ensures that 65% of the CICs profits are reinvested back into the company or used for the community it was set up to serve. Unused dividend capacity can be carried forward for five years.

In BenComs, any profit has to be used for community benefit and cannot be distributed amongst members. However, BenComs are permitted to pay interest to shareholders on the sums invested.

Asset Lock

Asset lock is a legal provision that stops the assets (including any profits or other surpluses generated by its activities) of a CIC being used for private gain rather than the stated purposes of the organisation.

It is a fundamental feature of CICs. It is important to fully understand this concept before opting for a CIC structure, as the asset lock is permanent and cannot be removed.

Asset lock means the CIC's assets must either be retained within the CIC to be used for the community purposes for which it was formed, or, if they are transferred out of the CIC, the transfer must satisfy one of the strict requirements:

- It is made for full consideration, which means assets are sold for market value (so that the CIC retains the value of the assets transferred);
- It is made to an asset locked body (another CIC, a charity or a Bencom with an asset lock) which is specified in the CIC's articles of association.

- It is made to another asset locked body with the consent of the Regulator; or
- It is otherwise made for the benefit of the community.

It is important to note that the asset-lock does not prevent CICs from using the assets in pursuit of community benefit. For instance, a CIC would be able to use assets as collateral to raise debt finance.

Once a CIC is incorporated, it will continue in existence unless it converts to a charity, or is dissolved. If a CIC is dissolved, any assets remaining after distribution will be transferred to another asset locked body, as described above, to be used for a similar community purpose.

When a BenCom with issued shares and an asset lock provision is dissolved, any outstanding creditors must be paid and the remaining shares will be repaid to members. Any remaining assets will pass to another asset-locked body.

7.2.5 Funding and Finance

In order to develop a community-owned network, it will be necessary to secure funding and finance. It should be noted, however, that there is a difference between these two things.

Funding is essentially a fixed, non-repayable amount of money that is used for a specific purpose within a project or enterprise. Grants and vouchers are examples of funding.

Finance is essentially an investment is expected to generate a return. Finance is needed to cover all or a part of the capital and working capital requirements, with operational expenditure met through revenues.

Community Enterprises are well placed to access funding of different types from different sorts of organisations. Funding may be philanthropic and support core or project-based costs, government funding to develop new technologies, business models, innovations etc, and other types of business support funding from other agencies such as Scottish Enterprise. Please see Table 7.2 for further examples of funding.

Table 7.2: Some examples of funding for Community Enterprises.

Funding type	Useful for	Examples
Philanthropic	Core costs and project costs	Joseph Rowntree Charitable Trust
		Esmée Fairbairn Foundation
		Other national, local and regional, philanthropic grant makers.
Government	Innovation	Government departments (DCMS, DEFRA, BEIS etc)
	Contracts to deliver services	
Other agencies	Business establishment and support	Scottish Enterprise, Local Authorities, Growth Hubs, LEPs, Devolved Institutions,
	Early stage research	Innovate UK

Funding type	Useful for	Examples
	Innovation	UKRI, Innovate UK, KTP
	Feasibility studies	Local and domain specific Arm's Length bodies
	Capacity building	
Tax and Voucher schemes	Correcting market failure	Market and Policy mechanisms, R100, Gigabit Vouchers
	Supporting vulnerable and excluded	
	Supporting research	R&D Tax Credits, Patent Box
	Supporting investment	SEIS and EIS

There are several approaches to financing Community Enterprises, with a number of different instruments available. It is possible to raise capital through shareholder equity, community shares, bonds, term debt and bridge debt.

Exactly which instruments are available to any specific Community Enterprise will depend on the type of incorporation it has. A Community Benefit Society (BenCom) for example, is unable to sell equity in itself – there are no shareholders. Some Community Interest Companies can raise capital through equity sales, but there are restrictions on the amount of dividend than can be distributed.

Structure should also be considered, it can be possible for some types of entity to own different types, which can unlock different types of financing. A Community Benefit Society may own a Private Limited Company, and be its sole shareholder, or one of its shareholders, it could also own a Community Interest Company (limited by share capital), but not a Community Interest Company (limited by guarantee). A Community Interest Company cannot own a Community Benefit Society though.

A nuanced interplay between finance and structure will always require specialist advice and detailed scrutiny.

Table 7.3 shows the different types of instrument and which organisations they are available to. As can be seen, the significant difference us around the issuing of equity.

Table 7.3: Financing instruments and type of organisation for which they are applicable.

Instrument	CIC Ltd by shares	CIC Ltd by guarantee	BenCom
Shareholder equity	✓		
Community Shares	✓	✓	✓
Bonds	✓	✓	✓
Term debt	✓	✓	✓
Bridge debt	✓	✓	✓

The more finance required and the more complex any structure is, the greater the professional fees costs can be expected to be. It is important for any Community Enterprise starting out to neither box themselves into a structure that will be unsuitable in future, but neither engineer something more complex than is needed to simply get started.

Table 7.4 shows potential funding and finance strategies at various stages of business growth.

Table 7.4: Funding and Financing needs vary at different stages of business growth.

<table>
<tr><th>Start Up</th><th>Early Stage</th><th>Growth</th><th>Established</th></tr>
<tr>
<td>Phase Description
• Resourcing
• Systems & processes establishment
• Customer acquisition
Finance Needs
• Assets & infrastructure acquisition & installation
• Operational working capital
Finance Strategy
• Maximize grants and local sources of capital friendly to your goals
Finance Sources
• Grants – government, philanthropy & other
• Local finance via community equity, development trusts, community bonds
• Joint venture arrangement between existing entity & local authority
Tax Relief
• Maximize tax relief via SITR or SEIS</td>
<td>Phase Description
• Focus on strong delivery
• Refine business model & operations
Finance Needs
• Operational working capital
Finance Strategy
• Work with existing sources of capital
• Bring in additional grants if available
• May require overdraft arrangement for working capital
Finance Sources
• Grants – government, philanthropy & other
• Local finance via community equity, development trusts, community bonds, local authority investment
• Joint venture arrangement between existing entity & local authority
• Overdraft from bank or credit source
Tax Relief
• Maximize tax relief via SITR or SEIS</td>
<td>Phase Description
• Focus on strong delivery
• Refine business model & operations
Finance Needs
• Capital for growth and acquisition of additional assets
• Ongoing working capital needs
Finance Strategy
• Expand with local sources of capital, if available. If not, explore debt and additional equity from broader domains
Finance Sources
• Local finance via community equity, development trusts, community bonds, local authority investment
• Traditional debt
• Broader sources of equity, including core customers
• Possibility of receivables discounting, too
Tax Relief
• Maximize tax relief via EIS</td>
<td>Phase Description
• Continuous improvement in service delivery
Finance Needs
• Capital for growth and acquisition of additional assets
• Ongoing working capital needs
Finance Strategy
• Expand with local sources of capital, if available. If not, explore debt and additional equity from broader domains
Finance Sources
• Local finance via community equity, development trusts, community bonds, local authority investment
• Traditional debt
• Broader sources of equity, including core customers
Tax Relief
• Maximize tax relief</td>
</tr>
</table>

8 Rural Connectivity Toolkit

A key output of the 5G New Thinking project is an on-line Rural Connectivity Toolkit that serves as a practical guide for rural and poorly-connected communities who are considering building and operating their own next-generation communications networks. It is the culmination of two years' work by private, public and academic consortium members, and it builds upon the learnings and insights from the 5G RuralFirst project that was undertaken in 2018-2019. (Figure 8.1 shows some screenshots from the Toolkit.)

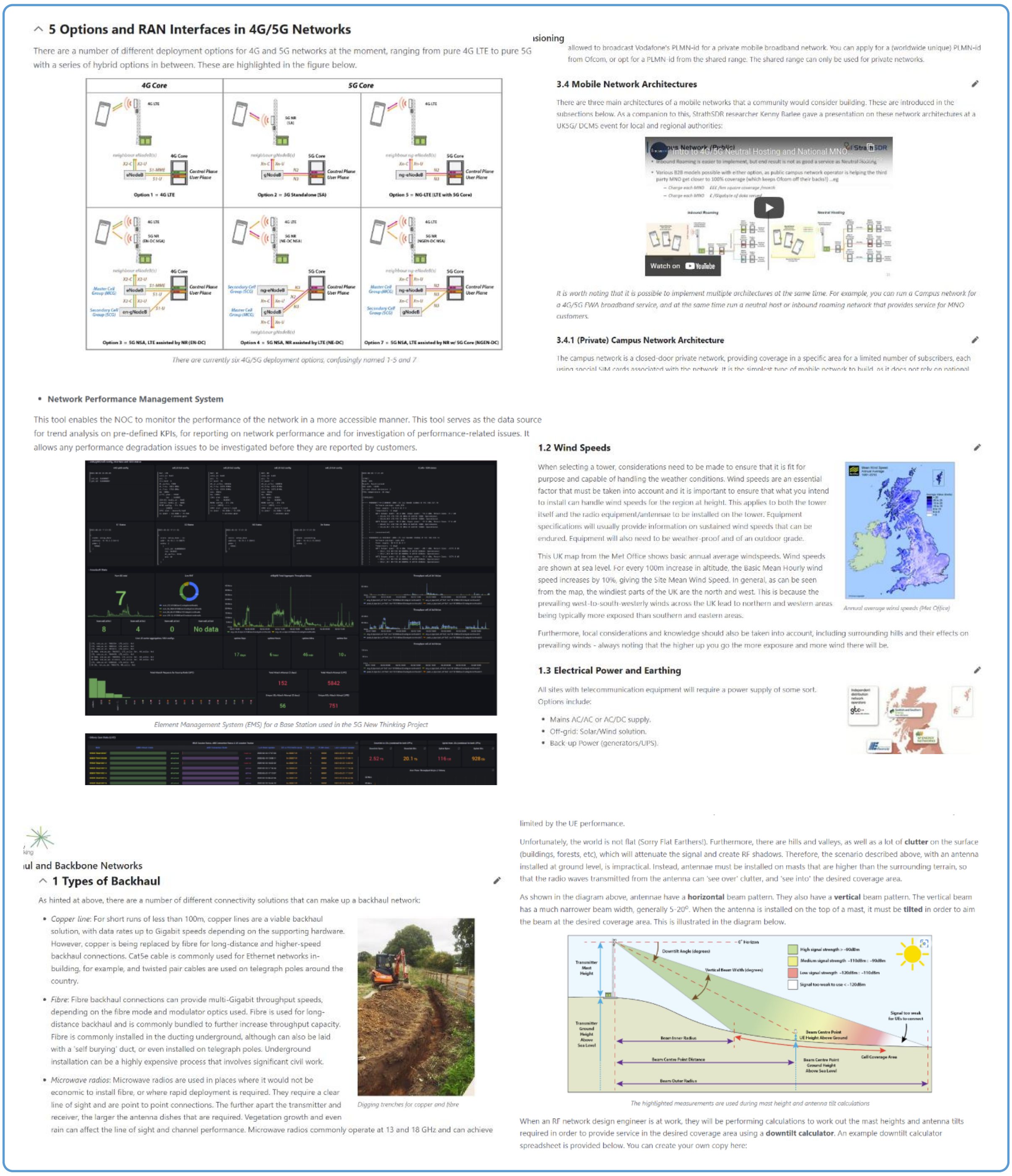


Figure 8.1: Some screenshots from the 5GNT Rural Connectivity Toolkit.

8.1 Implementation

The Toolkit is implemented on a Media Wiki platform which contains information and guidance aimed at helping communities to create a business plan, design and build a network, and subsequently operate the network and run the business. It also provides interactive tools, including cost and feasibility analysis tools and market-leading local and shared access spectrum tools. It is organized in a manner which closely resembles the structure shown in Figure 8.2.

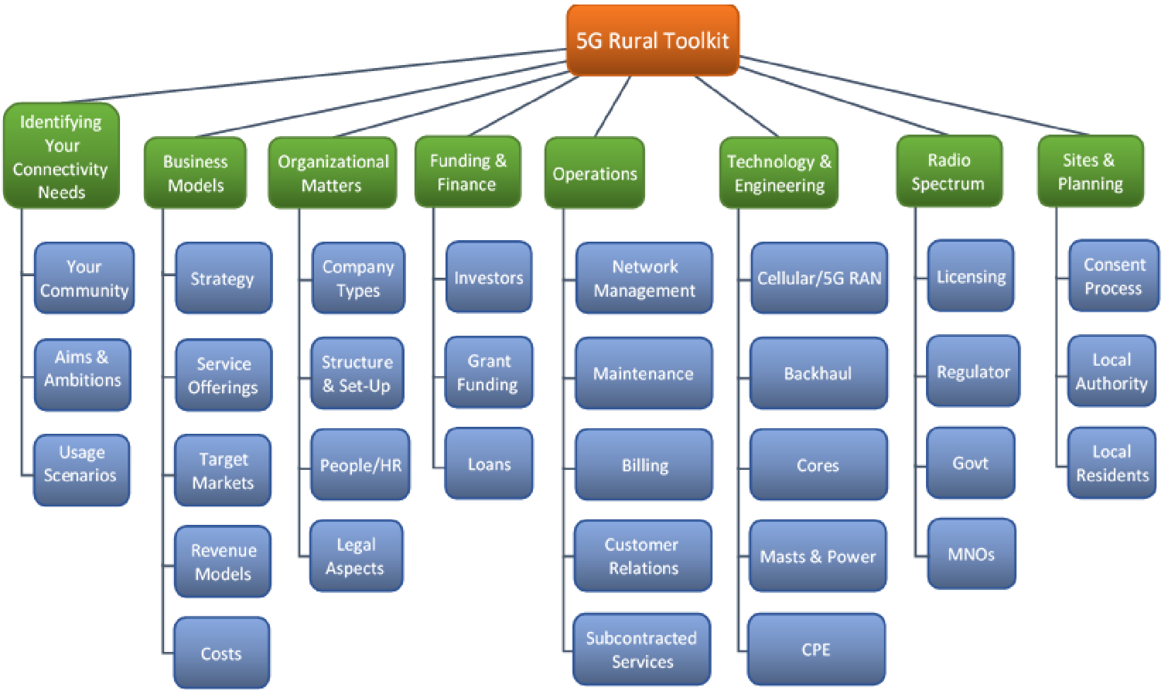


Figure 8.2: Organizational structure of Toolkit.

8.2 Accessing the Toolkit

The Toolkit can be accessed by visiting https://toolkit.5gnewthinking.org, where you will be presented with the 'Welcome' page, as illustrated in Figure 8.3. In order to view other pages, you will need to sign in or create an account if you don't already have one, and once signed in you will have access to all of the pages contained within the Toolkit.

8.3 Licensing and Open-Sourcing

The Toolkit has been made available under a Creative Commons licence, which fundamentally means that anyone can re-use and re-purpose any or all parts of the toolkit, with the licence condition and proviso that that they will fully credit and reference the original source.

Figure 8.3: Screenshot of Toolkit Welcome page.

8.4 A Closer Look At The Content

The Toolkit is built on the premise that there is much that communities themselves can do - with the right information and expert support - to enable digital connectivity in their areas. Each community is different though, with different connectivity requirements and coverage requirements, different operating environments, different inherent skills and capabilities, etc. However, the issues and challenges to be dealt with, and the key decisions that need to be considered, will broadly be very similar, and the Toolkit provides information on these, along with guidance on the key issues that are involved.

The content is structured according to the following high-level categories:

- **Create your business plan**
  In order to build a commercially viable and sustainable network, you will need to have a solid business plan that clearly defines how you will deliver digital connectivity services that meet the community's needs, and how this will be done in a way that is financially sustainable. This involves identifying your community's needs and the applications and use cases that the network will need to support, as well as working out business models, conducting cost/revenue analyses and setting up the community enterprise organisation that will secure the funding and finance you need to build and operate your network and 'run the business' going forward.
- **Plan and build your network**
  Your network will need to meet the needs of your community and do so in such a way that it is viable and sustainable from a commercial viewpoint and as well as from a practical point of view. Your network could include optical fibre runs, radio access networks, point-to-point microwave links, masts and electrical power facilities, all of which needs to be planned and designed. You will need to consider coverage and capacity requirements, end-user devices, access to radio spectrum, access to mast sites and associated planning consent, network security, and more.
- **Operate Your Network and 'Run Your Business'**
  In order to operate your network, you will need to define and establish processes and procedures for monitoring, managing, and maintaining the network and its

constituent components, as well as how you will manage customers and bill them accordingly.

Within each of these high-level categories, there is information and guidance on various subtopics, as illustrated in Figure 8.2. (It should be noted, however, that the Toolkit is a 'living' resource which is subject to modification and updating, so the topics and organization of content may vary from that which is illustrated in Figure 8.2.)

The Toolkit also provides interactive tools to help with spectrum planning and licence applications, as well as business modelling and financial analysis. (See Figure 8.4, for example.) These are key considerations for any connectivity solution that aims to be sustainable and viable.

Equity %	0%
Debt %	100%
WACC	5.00%

Year	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Income													
Income		£ 31,500.00	£ 31,500.00	£ 39,500.00	£ 39,500.00	£ 39,500.00	£ 39,500.00	£ 39,500.00	£ 39,500.00	£ 39,500.00	£ 39,500.00		
Expenditure													
OPEX		£ 11,626.70	£ 11,626.70	£ 11,626.70	£ 16,626.70	£ 16,626.70	£ 19,126.70	£ 19,126.70	£ 19,126.70	£ 19,126.70	£ 19,126.70		
P/L		£ 19,873.30	£ 19,873.30	£ 27,873.30	£ 22,873.30	£ 22,873.30	£ 20,373.30	£ 20,373.30	£ 20,373.30	£ 20,373.30	£ 20,373.30	£ -	£ -
Capital Investment	£ 71,250.00												
Cash Flow (Annual)	-£ 71,250.00	£ 19,873.30	£ 19,873.30	£ 27,873.30	£ 22,873.30	£ 22,873.30	£ 20,373.30	£ 20,373.30	£ 20,373.30	£ 20,373.30	£ 20,373.30	£ -	£ -
Cash Flow (Cumulative)	-£ 71,250.00	-£ 51,376.70	-£ 31,503.40	-£ 3,630.10	£ 19,243.20	£ 42,116.50	£ 62,489.80	£ 82,863.10	£ 103,236.40	£ 123,609.70	£ 143,983.00		

NPV	
5.00%	£91,077.97
7.00%	£75,468.66
10.00%	£56,329.13
IRR	27.94%
SPY	5 Years

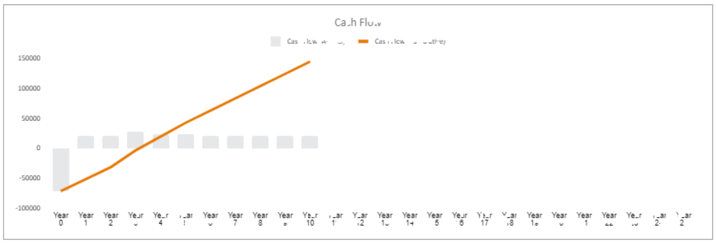


Figure 8.4: Screenshot of NPV analysis tool.

8.5 Summary

The 5G New Thinking Rural Connectivity Toolkit serves as a practical guide for rural and poorly-connected communities who are considering building and operating their own next-generation communications networks. It covers a wide range of key topics encompassing business planning, building the network, and subsequently operating the network and running the business. Each community is different though, and there is no 'one size fits all' solution. Nevertheless, the Toolkit provides information and guidance on the key issues and decisions that need to be considered. It can be accessed by visiting https://toolkit.5gnewthinking.org.

9 Collaboration

This section describes the collaboration activities in which the 5G New Thinking project engaged within the DCMS 5G Testbeds & Trials (5GTT) Programme.

Key areas that were identified for collaboration near the beginning of the project included **Neutral Host** operating models, **spectrum sharing**, and **5G safety and public perception**. This describes our collaboration efforts in these key areas, along with collaborative aspects of a series of stakeholder workshops which were organized and run by the 5GNT project consortium at various times throughout the project.

9.1 Neutral Hosting

A key aim of 5G New Thinking was to establish if there is a way for rural communities to build and operate their own radio networks in such a way that they can be utilized by national Mobile Network Operators (MNOs) to enhance their service coverage. Following discussions with other 5GTT projects and with some consortia submitting 5G Create bids, we agreed, in principle, to collaborate on a number of relevant topics, including:

- **Architectures** – understanding how radios must be built in order to connect to an MNO's core;
- **Operations** – understanding how radios must be operated and exposed to MNOs in order to deliver on a viable service experience;
- **Economics** – understanding the costs, revenues and key variables that can be expected by such deployments.

Much of this understanding has been incorporated into presentations and other knowledge dissemination activities, such as a presentation on Neutral Hosting given on 1st March 2022 at a UK5G/DCMS Place Event Series seminar and, of course, the 5GNT Rural Toolkit, as illustrated in Figure 9.1.

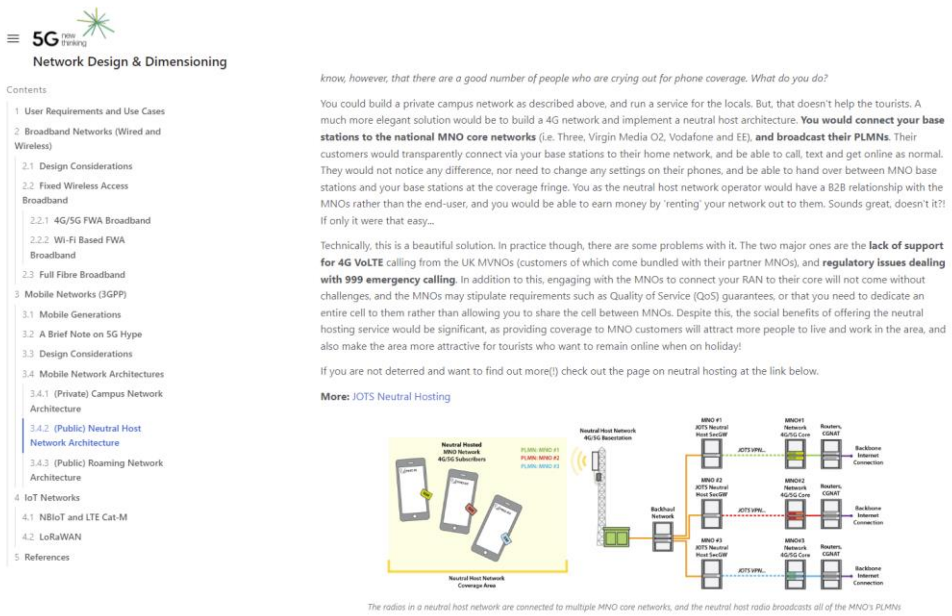


Figure 9.1: Extract from 5GNT Toolkit, discussing Neutral Hosting.

9.2 Spectrum Access

Affordable access to suitable radio spectrum is a key issue for any rural community that aims to build its own network. Traditionally, it has been extremely difficult for communities to obtain access to suitable spectrum, even when it is not being used in their particular locations. This issue has been alleviated, to a certain degree, by Ofcom's introduction of Local Access Licences (LALs) and Shared Access Licences (SALs) in 2019. In practice, however, obtaining LALs and SALs has not necessarily been as straightforward as might have been expected, and the commercial viability of making use of these licences yet to be proven.

In 5G New Thinking we have been working on various approaches to promote and advance progress in spectrum sharing. We have made various representations to Ofcom in order to explain our activities and present our thoughts and proposals to them, and we have developed tools to help communities to identify candidate frequencies and apply for licences. We have also been in discussion with the MoD to discuss and demonstrate dynamic spectrum access and spectrum sharing (DSA) in the context of the SAL tools and the use of regulator overrides and fully-automated DSA whereby prioritized users could rapidly reclaim spectrum as needed by area/time/band.

A key theme of our proposals involves the adoption of automated techniques for dynamic access to spectrum, and we have contributed to the "Ofcom Shared Access Licence: 5GTT Implementation and Learnings Report" prepared by the DCMS/UK5G-led group "Access licensing - lessons learnt and best practice".

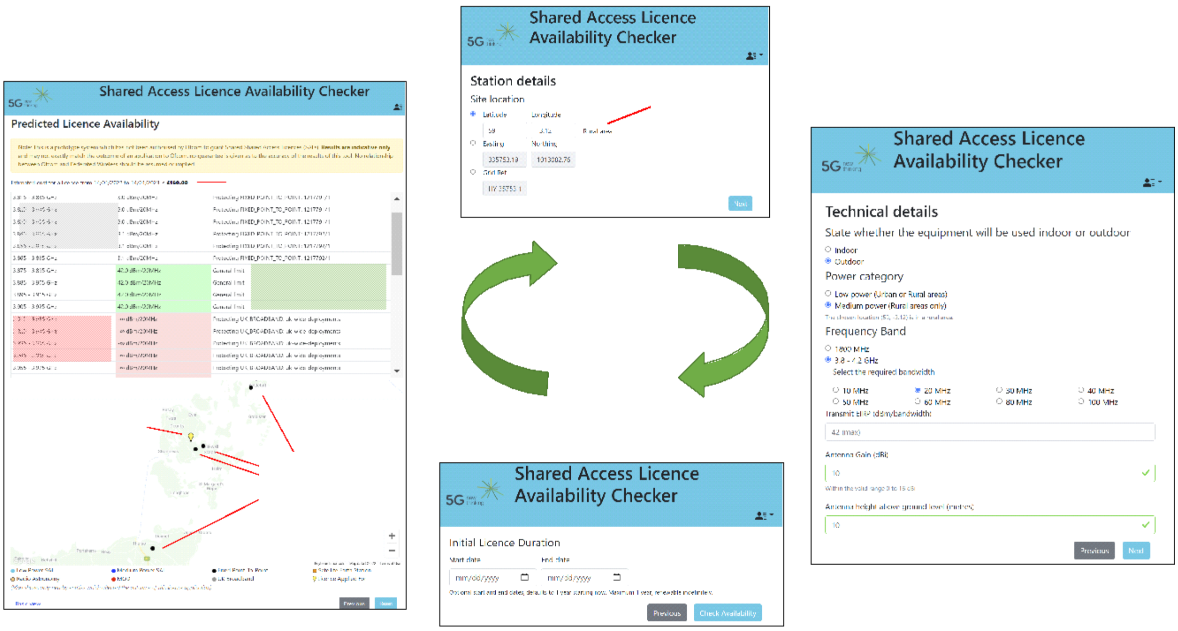


Figure 9.2: Extract from draft document: "Ofcom Shared Access Licence: 5GTT Implementation and Learnings Report", showing Federated Wireless RAPID SAL on-line application tool.

5G New Thinking was also represented at the "5G Shared Spectrum for Private Networks" event which was hosted, on line, by the University of Strathclyde on 28th October 2021. The event was attended by over 140 people from industry, government, and public sector organizations.

Looking towards the future, beyond 5G, we have been collaborating with the UK Spectrum Policy Forum (SPF) and the UK Universities 6G Spectrum Research Initiative. While there is much talk about the GHz and THz bands for 6G, we have been promoting many of the ideas and concepts being developed by 5G New Thinking in relation to more efficient and more effective access to spectrum in the lower- and mid-frequency bands. A key theme here is that spectrum policy for 6G needs to build upon and extend the developments that have been made for 5G spectrum access.

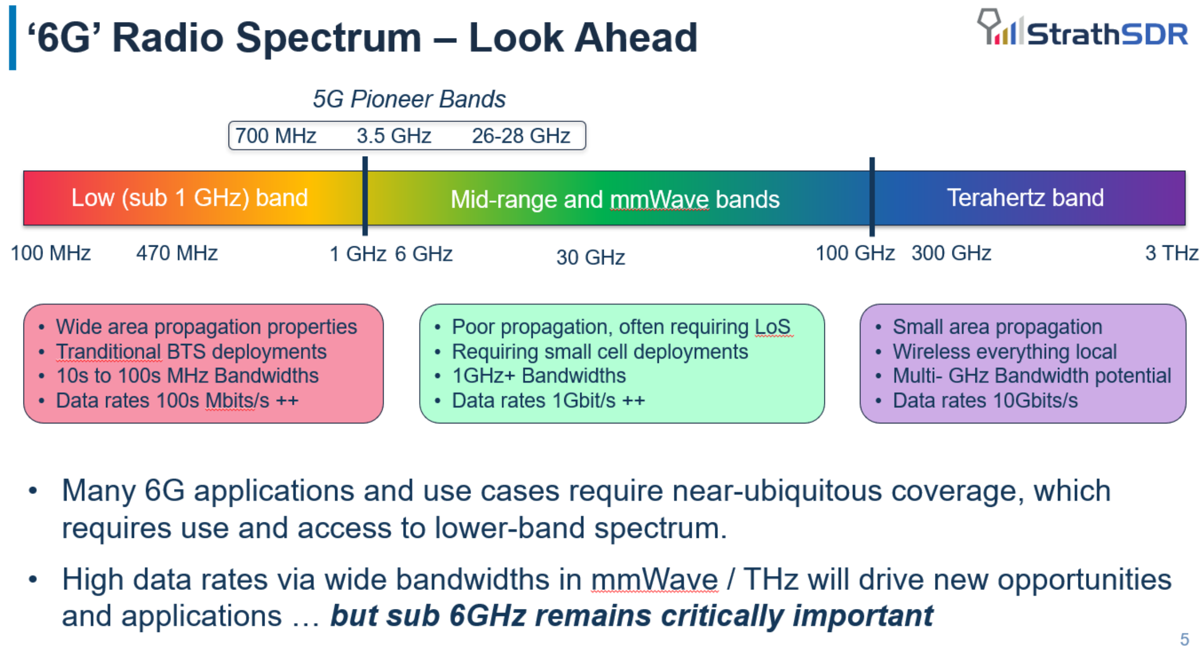


Figure 9.3: Extract from presentation given at 6G spectrum event in May 2021.

9.3 5G Safety

Health & Safety concerns surrounding the use of 5G technologies have gained momentum in some quarters in recent years. Initially, these concerns were driven by perceived uncertainties related to new 5G frequency bands in the region of 26-28 GHz (so-called mmWave bands); however, they have since grown to encompass all things 5G, and there have been several recent incidents involving mobile basestations being vandalised and set alight by anti-5G protestors. (Many of the basestations targeted by protestors have not actually been 5G basestations.)

To a large extent, such concerns are fuelled by lack of knowledge and understanding, often accompanied by a mistrust of the mobile industry and even international organizations such as the World Health Organization (WHO) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Nevertheless, we have to recognize that the question of health and safety is, in itself, genuine. And the rights and expectations of people to have informative answers and explanations given to them are entirely legitimate. It is therefore important that projects such as ours, and the industry as a whole, take such concerns seriously and make genuine efforts to address them in an open and transparent way.

5G New Thinking has contributed to the discussion on how best to deal with such issues and concerns. It was recommended that UK5G produce content to help educate and inform people of the issues related to 5G safety and to try to present a balanced and reasoned perspective on the matter. We have also incorporated relevant content in the 5GNT Toolkit, as illustrated in Figure 9.4.

Figure 9.4: Extract from 5GNT Toolkit, discussing '5G and Public Health'.

9.4 5G Stakeholder Events

During the 5G New Thinking project, three stakeholder workshops were held, involving stakeholders and collaborators from industry, government, local authorities, community organizations, and academia. The workshops, which were all held on line due to Covid restrictions, covered key topics related to community connectivity solutions and networks:

- **Workshop 1:** 5G Connectivity: A Journey for Rural Communities (November 2020).
- **Workshop 2:** Funding & Finance Options (February 2021).
- **Workshop 3:** MNO Interactions and Best Practice Engagements (June 2021).

Further information on these workshops can be found in Section 5.

In addition, 5GNT teamed up with O2 to jointly co-host the table on Neutral Hosting at the DCMS 'Be Better Connected' event which ran on the 23rd and 24th March 2021.

10 Key Findings and Lessons Learnt

5G New Thinking has explored numerous issues related to the provision of digital connectivity in hard-to-reach rural areas, from technical aspects of building neutral host networks to business models for community-owned and operated networks; from spectrum access to mast site access and planning consent. We have also explored a range of use cases and applications, including agri-tech, healthcare, and temporary/pop-up networks.

These activities have led to a number of findings and lessons learnt, which we describe in this section. We have tried to categorize them where possible, although we recognize and acknowledge that there may be overlaps and dependencies between categories. The categories are presented below in no particular order.

10.1 Practical Challenges of Deploying in Remote, Rural Locations

Many of the challenges associated with deployment in remote, rural locations are already well known from previous projects. Within 5G New Thinking, some of the challenges faced with deployment on remote island locations included:

- Some particularly remote islands do not have facilities to support Roll-on-Roll-off (Ro-Ro) ferries, and the transportation of machinery and materials to such islands relies on the use of cranes to load and unload boats. This has to be pre-arranged, and the cost and time associated with this have to be taken into account during the planning stages.
- Transport on ferries is subject to delay and cancellation at short notice due to weather. As a result, all plans need to have flexibility and contingency built into them. A 2-day install might end up taking more than a week, and personnel can become ‘stranded’ on site with no way of returning home until the weather allows for transport services to be resumed. If they had been scheduled to do other installs during this time, other arrangements will need to be made.
- Equipment can break down, and there may be no practical access to repair facilities. On one particular occasion within 5G New Thinking, a mobile crane broke down after arriving on a remote island with no garage/mechanic services. The only viable solution was to wait a few days for a replacement crane to arrive. This costs time and money, and it has a knock-on effect on plans and schedules.

10.2 Backhaul Infrastructure

Good 5G coverage (or even 4G coverage for that matter) requires adequate backhaul infrastructure. In many rural settings, this will require backhaul to be provisioned specially for the network, but it should be borne in mind that ordering Direct Internet Access (DIA) backhaul circuits from suppliers and the national incumbent, BT, can be a lengthy process. You may need to dig your own trenches and lay your own fibre for part of the route, and you may also consider using point-to-point microwave links where appropriate. Bear in mind, though, that microwave links may require spectrum licences, and the cost of these needs to be factored in to your plans. (The costs will depend on a number of factors, including the particular frequencies and bandwidths used.)

10.3 Planning Consent

Planning consent applications can be lengthy and difficult to predict. The Local Authority's planning department will have a process for dealing with planning applications, but some steps are conditional on the outputs of previous steps and it is difficult to predict the exact pathway that will end up being followed. External influences such as objections may cause delay, and it will usually require effort to address and respond to them. Environmental concerns may play a part, too. For example, in one location, we had to respect and accommodate the nesting season of protected birds and ensure that all work took place outwith the nesting season. In another location, we had to arrange for a peat survey to be carried out to ensure that our civil works would not disturb any peat lands. All of this has the potential to introduce delay and expense, and has the ability to disrupt plans and schedules.

10.4 Covid Made Everything More Difficult

The restrictions imposed as a result of Covid presented a number of challenges. For example, with offices and laboratories closed and many people working from home during much of 2020 and 2021, all project meetings had to take place virtually, and although this worked well, the lack of face-to-face meetings was nevertheless a limiting factor on the smoothness of design decisions and other planning and implementation decisions.

Many materials became scarce, and lead times for what would normally have been regarded as 'stock items' sometimes became prohibitively long. This not only presented a risk to plans and schedules, it also made it necessary for us to devote unplanned time and effort trying to find alternative sources for such items, and in some cases we had to pay a price that was significantly higher than originally expected.

Furthermore, with 'goods in' staff working from home, it often became a challenge taking delivery of items (and tracking them down) when they did arrive on our premises. Eventually, we found that it was easier to have many items delivered direct to people's homes, but such items then became accessible by only one person to work on, and in any case, there are practical limits to the number of radio units and antennas that can fit into a living room or hallway without causing domestic tensions, made worse by the fact that the kitchen table has also been re-purposed as a makeshift workbench!

When the offices and labs did eventually start to open up gradually again, and visits to sites started to become possible again, there was nevertheless a considerable amount of paperwork and approvals required in the form of risk assessments etc., and this, too, consumed time and effort that hadn't been planned.

In a nutshell, Covid restrictions essentially meant that **everything took longer** and we had to **expect the unexpected**.

10.5 Use Case Trials on Farms Are Challenging

Use case trials on farms are difficult to implement – not only because of the technical and supply-chain difficulties, etc., but also because of the dependency on seasonal schedules; for example, cows will only be indoors at certain times of the year; the crop production cycle is seasonal, etc. Use Case trials need to coincide with these seasonal events, and when this is not possible, it may become necessary to wait until the following year before the opportunity presents itself again. This presents obvious challenges for Use Case trials that are scheduled to be less than 12 months in duration.

10.6 Handset Features and Functionality

Shortly after the project commenced, it became apparent that DCMS could not support the purchase of equipment from 'High-Risk Vendors' (HRVs) for use in the project. We subsequently found that many alternatives did not have the same levels of performance, despite being more expensive. Furthermore, we particularly found that the features and capabilities of a number of consumer handsets were not aligned with what was being claimed in the datasheets and sales brochures. (Modem modules, on the other hand, tend to be more 'reliable' in this regard.)

In some cases, it appears that handset features are being enabled selectively according to the SIM's IMSI. (This is effectively carrier-based feature selection.) For example, certain features may be available when an EE SIM is inserted but not available when a Private 5G Network SIM is inserted.

In other cases, the firmware on the handset is disabling features (such as bands, NSA and SA attaches), and replacement firmware versions are not always available. Even when alternative firmware was provided, said features were not always enabled anyway.

Although we managed to devise workarounds for these issues, they nevertheless have implications for private 5G network deployment in general.

10.6.1 Phone Handset Firmware and Carrier Customisation

Mobile phones are shipped either 'carrier locked' or 'unlocked'. Carrier locked phones contain firmware that has been customised by the carrier (i.e. the MNO), and they are normally sold by the carrier to the end user with contract packages.

Carrier locked phones permit only SIM cards issued by the carrier to be used, and will have some of the phone hardware's RF capabilities disabled in order to 'focus' the device on the spectral bands which the carrier is licensed to use. Parameters for GSM, CDMA, LTE and NR are configured. Preferred cellular channel numbers (ARFCN/EARFCN/NR-ARFCN) are often programmed to enable rapid scanning. The carrier's 4G APN and 4G VoLTE/VoWi-Fi calling parameters are also preloaded on these phones.

In contrast to this, 'unlocked' phones are sold without carrier parameters pre-configured on them. They will normally support 2G & 3G calling/SMS/data connections and 4G data connections for all networks, including private networks, out-of-the-box. On inserting a carrier's SIM card to an 'unlocked' phone, a process called *Technical Adaptation of Devices (TAD) through Late Customization* is initiated (GSMA TS.32[17]).

The TAD process essentially reconfigures the unlocked phone, turning it into something akin to a carrier locked phone once again. (These changes are reversible through a factory reset). TAD sees the phone's RF capabilities changed, enabling and disabling support for particular bands. For example, with a UK carrier SIM, LTE Band 20 (800MHz) would be enabled, while a USA carrier SIM would enable LTE Band 5 (850MHz). Carrier APNs are

[17] See: https://www.gsma.com/newsroom/wp-content/uploads//TS.32-v8.0-1.pdf

automatically loaded, and parameters relating to 4G VoLTE/VoWi-Fi calling are configured on the phone, enabling calling over 4G and Wi-Fi connections.

Ofcom has banned the sale of carrier locked phones in the UK since December 2021[18], and the TAD customisation mechanism has become the primary method for carriers to configure devices.

Operators of small or private networks often do not have the scale required to qualify for OEM carrier locking or OEM TAD configurations. Implications of this include:

- When a private network SIM card is inserted to an unlocked phone, the phone will attach to 2G and 3G cells only. APN settings must be manually configured to enable a 4G attach. If the private network is 4G/5G only, the phone will only support 999 calling via emergency attach onto third party (MNO) networks until the APN settings are entered. This is not of huge concern, but it comes with technical support issues.
- When connecting an unlocked phone to a private 4G/5G network, there is a significant probability that the phone will not support 4G VoLTE or VoWi-Fi calling. This is because without automatic TAD, there is no process to reconfigure the VoLTE or VoWi-Fi calling parameters. Some workarounds for Android devices have been presented by the open-source community; however, these require the 'rooting' of the phone, which voids warranty and commonly permanently disables software and security updates on the device. In general, therefore, 4G VoLTE/VoWi-Fi calling will typically not be possible on private networks.
- There have been reports of advertised '5G NSA capable' unlocked phones refusing to attach to NR cells for certain operators, even though the same phone will happily attach to similar cells from another operator following a SIM swap and factory reset. This indicates that some device manufacturers are shipping unlocked 5G phones that do not support 5G NSA dual connectivity without TAD. This is a cause for concern, as it will act as a barrier to the rollout of private 5G NSA networks.
- During the life of the 5G New Thinking project, we tested six phones from a range of manufacturers (both Android and iOS based) that claimed to support '5G SA'. Not a single one of these supported SA attaches out of the box on our private 5G SA network. None of them even showed evidence of scanning for a 5G SA network, and there was no communication with the gNB over the air. We tried this with a variety of bands, including bands we knew the devices definitely supported. One of the phones tested here was a Samsung S21 5G. A second Samsung S21 5G, sourced via a tier 1 partner, had an alternative firmware version on it. This phone was truly unlocked, with all features enabled. As a result, this device happily attached to our network. As with the 5G NSA point above, this indicates that some device manufacturers are shipping 'unlocked' 5G phones that do not support 5G SA without TAD. This is a cause for concern, as it will act as a barrier to the rollout of private 5G SA networks.

The key concern here is that small operators and operators of private networks will face issues with the customisation of phones when deploying 4G/5G networks, and this will have

[18] See: www.ofcom.org.uk/news-centre/2021/mobile-companies-now-banned-from-selling-locked-handsets

an impact on the business models and viability of private networks which seek to make use of consumer mobile handsets.

10.7 Spectrum

At the beginning of the project, we set out to explore the practical aspects of obtaining access to spectrum via the Local Access Licence (LAL) and Shared Access Licence (SAL) methods that were introduced by Ofcom in 2019. We also wanted to develop a set of tools to help with the task of identifying spectrum for potential use and preparing a licence application for it. Here, we give some insight into our experiences and reflections on this:

- Without documenting a process, users cannot make reasonable predictions about the likely outcome of the process nor the time required to complete the process. Investments that depend on such an uncertain process will necessarily be limited. Furthermore, an undefined/unclear process is a poor candidate for streamlining via software. Making this point more specific to the program, one of the reasons the LAL process streamlining and the applications in general failed is the lack of clarity over what is needed to secure MNO approval of a LAL application. In practice, it seems that direct business-to-business subleasing/negotiation will be superior to the LAL arrangement. In contrast, the SAL application process was defined in detail and we believe our software tool has been successful in streamlining the process to the extent possible.
- MNOs lack reasonable incentives to support LALs. Beyond the immediate access issues, this also impacts the incentives to document agreeable access processes.
- There are privacy and security constraints that limit Ofcom's ability to publish certain site information that would facilitate spectrum sharing calculations. However, no such constraint appears to exist for publishing coverage data, which would suffice for spectrum sharing calculations and would probably be of greater public interest than tower and antenna data.
- Published SAL coexistence calculations for medium power sites with directional antennas are inefficient. Significant gains in capacity and access could be achieved by accounting for horizontal and vertical gains.
- First-come-first-served licensing is beginning to emerge as a problem for SALs, where there are some regions (e.g. Sheffield/Leeds) that are sufficiently built out as to limit access for new applicants, at least for wideband medium power outdoor uses.
- The protection of incumbents in the SAL bands (PES, fixed link, MoD...) does not significantly limit shared access or capacity across the UK in general, although fixed links do constrain medium power outdoor SALs around the northern islands.

10.7.1 Impact of LAL Tool

Relatively little impact from the LAL tool was seen. Largely, this is due to the opacity and uncertainty inherent in the LAL application process (specifically MNO coordination), which makes LALs a risky path to network deployment. However, the application management dashboard and PDF generation capabilities are likely to be exported from the LAL tool and imported to the SAL tool as additional services become available beyond the "freemium" spectrum inquiry capability of the currently available SAL tool.

10.7.2 Impact of SAL Tool

The SAL tool eliminates the most common application errors (disallowed combinations of parameters, attempting a medium power SAL in an urban area) and gives feedback to applicants in seconds as opposed to the month+ that is required for Ofcom feedback.

These gains have opened several doors for business development for Federated Wireless (the 5GNT partner who led on the development of the LAL and SAL tools), including:

- Opportunities for joint private network deployments in SAL bands with UK WISPs and some joint US (CBRS) / UK (SAL) private network / spectrum sharing initiatives.
- Collaboration opportunities related to 3D spectrum sharing across terrestrial, airborne and satellite communications networks with European researchers.
- An invitation to respond to the MoD solicitation on Government Controlled DSA.
- Identification of a path to insert the SAL tool into Ofcom spectrum management processes in the future.
- Providing additional capabilities for the SAL tool for subscribed users under a freemium model.
- Potential for tool transition overseas for streamlining access to other SAL-like bands.
- Recognition for the SAL tool as a finalist for the 5G Showcase Best Business Impact Award 2022.

11 Summary & Conclusions

5G New Thinking (5GNT) has been an ambitious project that has involved 18 consortium partners working with a number of rural communities across the UK to devise different approaches to help solve the rural connectivity challenge. The consortium developed a 5G testbed network that was built in two remote island locations in Orkney, as well as a number of other testbeds and use case trials in areas such as agriculture and healthcare.

The project explored a range of issues and challenges related to the provision of digital connectivity in hard-to-reach rural areas, encompassing technical aspects of building neutral host networks, business models for community-owned and operated networks, spectrum access, mast site access and planning consent, etc.

A key output has been an on-line Rural Connectivity Toolkit[19] that enables remote communities to learn more about the option of 'self-provisioning' for their mobile and wireless connectivity needs. This reflects many of our findings and lessons learnt, and it serves as a practical guide for rural and poorly-connected communities who are considering building and operating their own next-generation communications networks. It covers a wide range of key topics encompassing business planning, building the network, and subsequently operating the network and running the business.

Enabling digital connectivity in rural areas is challenging – if this were not the case, the mainstream national network operators would already be providing service in such areas. For example, suitable locations for mast sites are often difficult to access and it can be difficult to get equipment to them; cable runs (for optical fibre, electrical power, etc.) can be long and expensive to install; customers are sparsely populated, which makes establishing a business case more difficult. But these hurdles are surmountable, and there is much that communities themselves - with the right information and expert support - can do to enable digital connectivity in their areas.

Each community is different though, and there is no 'one size fits all' solution. Nevertheless, the 5GNT Toolkit provides information and guidance on the key issues and decisions that need to be considered and addressed, and while this does not necessarily guarantee that a commercially viable and sustainable network can be built and operated in every instance, it allows interested individuals to explore what it would take to build connectivity in their communities, and to make an assessment as to whether or not this could viably be done in their particular case.

Creating a financially viable and sustainable business is the key overarching challenge that will face any group of individuals seeking to address a lack of digital connectivity in a particular community. Many of the individual challenges associated with this are discussed in previous sections of this report and in the Toolkit itself. Here we present a brief summary of some of them, along with some thoughts on how they might be addressed – in some cases via wider involvement of government and key industry players:

- **Community Resources and Enthusiasm/Commitment**
  A key feature of projects where communities have developed their own connectivity networks is the presence of a group of committed people who drive the project

[19] https://toolkit.5gnewthinking.org/

forward. This group is usually formed of volunteers, particularly in the early phases of development. At a very early stage, you will need to consider the resources that your community has available and whether there will be sufficient support to drive a project forward. In some communities, it may be relevant and appropriate to use existing community groups or structures as a starting point. These may be groups that are already formally constituted and have a board of directors from the community.

- **Business Structure and Organization**
  As your project develops, you will probably need to form an incorporated entity, such as a Community Interest Company or Community Benefit Society, which has a board of directors offering a good mix of relevant skills and experience. Ultimately, you are going to be running a business regardless of how you set up your community enterprise and how you resource it. And the usual rules of business apply, including the need to be commercially viable. However, depending on how you choose to run the enterprise and the legal structure that you choose for it, your priorities and aspirations, and the associated measures of success, might be different from those of a traditional corporate organization. For example, you might decide to prioritize social value over financial gain, and this would be reflected in the strategic decisions and choices made at each stage of set-up and ongoing development of the business. Also, certain community enterprise structures may have access to sources of funding and finance which other, more traditional organizations may not have. The same is true for community 'goodwill'.
- **Business Models and Product/Service Offerings**
  Every community is different, and so, too, are its connectivity needs. When developing an appropriate solution for your community's connectivity needs as part of your business planning activities, you will need to think about the features that are unique to your community. Population density, topography, existing connectivity arrangements and network resources, and socio-economic factors will all play a role in determining the approach and business model that is best suited to your community. The 5G New Thinking Toolkit has tools that can help you to explore different cost/revenue models and assess their viability. Our experience suggests that you will very probably need to consider multiple service offerings or 'layered' service provision, as building a network for a single use (e.g. for Fixed Wireless Access alone) is unlikely to be viable on its own. But this all depends on a number of factors, including your community's strategic priorities in relation to things such as social value vs financial gain, as previously mentioned.
- **Backhaul**
  Good 5G coverage (or even 4G coverage for that matter) requires adequate backhaul infrastructure. In many rural settings, this will require backhaul to be provisioned specially for the network, but ordering backhaul circuits can be a lengthy process, and the annual costs of backhaul and Internet connectivity can be high and need to be factored in to the business models. We explored the possibility of communities being given favourable access terms for Scottish 4G Infill masts, but this turned out not to be straightforward and the only option appeared to be simply to pay the full commercial market rate for backhaul.
- **Access to Radio Spectrum**
  Ofcom's Local Access Licence (LAL) and Shared Access Licence (SAL) mechanisms

represent a significant step forward in improving access to spectrum and improving overall utilization of spectrum. However, our experience suggests that more work is required to make such mechanisms work effectively as originally intended.

- We found that licences in LAL spectrum were difficult and time consuming to obtain. MNOs appear to lack reasonable incentives to support LALs, and there is a lack of clarity on what is needed to secure MNO approval of a LAL application. In addition, the default three-year duration makes investment decisions difficult, especially for rural areas where the business case is already marginal.
- Obtaining licences in SAL spectrum was slightly easier, but even here, the 'first come, first served' basis on which these are allocated is potentially limiting, particularly if the licence-holder doesn't need to use the spectrum continuously. An automated, DSA-like approach could potentially help to allow this spectrum to be genuinely shared among more than one user, and we recommend that this be given consideration.
- In some cases, it can make good sense to use point-to-point microwave links for backhaul connectivity to mast sites. However, these generally require their own spectrum licences, and the annual cost of these needs to be factored in to any business plan. The exact cost will depend on a number of factors, including the particular frequencies and bandwidths used, but they can end up becoming a significant proportion of the overall annual operating costs. One potential approach to alleviating this might be for Ofcom to consider the creation of special, reduced-rate tariffs for qualifying rural community organizations.

- **Neutral Hosting**
  In principle, Neutral Hosting has the potential to be an effective way of connecting a remote rural community network to one or more national MNO networks. This could allow local residents to make use of the same UE devices to access national MNO services throughout the UK when travelling, and it could also allow non-local MNO customers to access the local network when visiting the area. While research has indicated that MNOs are keen to roll out 5G in rural locations, there is some resistance towards working with rural neutral hosting providers, and commercial terms and conditions would need to be agreed. Whether MNOs would be willing to enter into such commercial arrangements with multiple local community organizations remains to be seen. Our experience would suggest that it seems unlikely, and future work is needed to work through the issues and come up with acceptable solutions. This may require government, regulator, industry, and potential neutral host providers to work together. Alternative approaches, such as the use of Dual-SIM handsets or local not-spot roaming, could be considered instead, but they have their own sets of pros and cons associated with them.

- **Handset Carrier Customisation**
  Operators of small or private networks often do not have the scale required to qualify for OEM carrier locking or OEM TAD configurations. Implications of this include:
  - When a private network SIM card is inserted to an unlocked phone, the phone may attach to 2G and 3G cells only. APN settings must be manually configured to enable a 4G attach. If the private network is 4G/5G only, the phone will only

support 999 calling until the APN settings are entered. This is not of huge concern, but it comes with technical support issues.

- When connecting an unlocked phone to a private 4G/5G network, there is a significant probability that the phone will not support 4G VoLTE or VoWi-Fi calling. This is because without automatic TAD, there is no process to reconfigure the VoLTE or VoWi-Fi calling parameters. Some workarounds for Android handsets have been presented by the open-source community; however, these require the 'rooting' of the phone, which voids warranty. In general, therefore, 4G VoLTE/VoWi-Fi calling will typically not be possible on private networks unless a solution is found.
- There have been reports of advertised '5G NSA capable' unlocked phones refusing to attach to 5G NR cells for certain operators, even though the same phone will happily attach to similar cells from another operator following a SIM swap and factory reset. This indicates that some handset manufacturers are shipping unlocked 5G phones that do not support 5G NSA dual connectivity without TAD. This is a cause for concern, as it will act as a barrier to the rollout of private 5G NSA networks.
- As with the 5G NSA point above, it appears that some device manufacturers are shipping 'unlocked' 5G phones that do not support 5G SA without TAD. This is a cause for concern, as it will act as a barrier to the rollout of private 5G SA networks.

The key concern here is that small operators and operators of private networks will face issues with the customisation of phones when deploying 4G/5G networks, and this will have an impact on the business models and viability of private networks which seek to make use of consumer mobile handsets. Resolving this may require regulatory intervention along similar lines to the banning of the sale of carrier-locked phones, which Ofcom introduced for the UK in December 2021.

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In conclusion, the 5G New Thinking project has explored a considerable number of factors related to rural connectivity and the use of 5G to alleviate the challenges. Challenges undoubtedly still remain, and some of these will require the involvement of government and key industry players working together to implement suitable solutions. Nevertheless, there is much that communities themselves can do, and our Rural Connectivity Toolkit provides communities with key ingredients and guidance for planning, designing, financing, building, and operating the infrastructure required to address their connectivity needs.

www.5gnewthinking.co.uk

toolkit.5gnewthinking.org

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