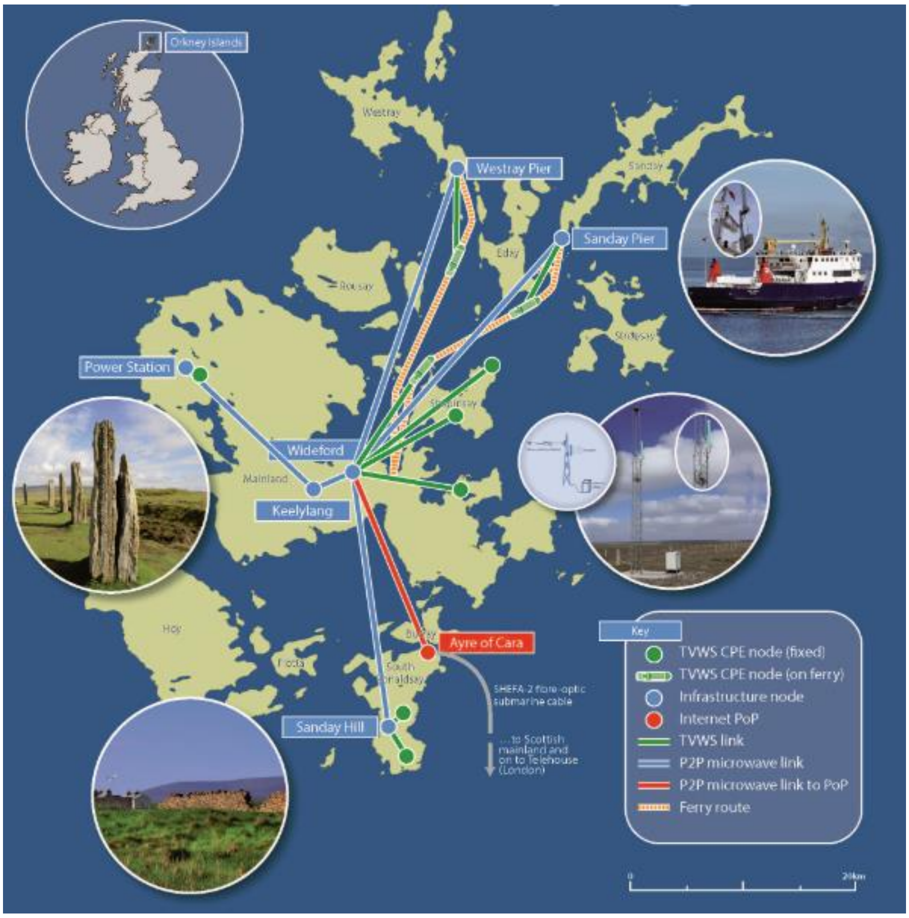
DEPARTMENT OF ELECTRONIC & ELECTRICAL ENGINEERING

University of Strathclyde Engineering

Orkney TV White Space Pilot

Centre for White Space Communications

Version 1.01



University of Strathclyde

CloudNet IT-Solutions Ltd

Scottish Futures Trust

Fairspectrum

BAE SYSTEMS INSPIRED WORK

6Harmonics

Orkney Ferries

The Scottish Government Riaghaltas na h-Alba

Orkney Islands Council

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Executive Summary

In September 2015, the Scottish Government awarded a grant to the University of Strathclyde's Centre for White Space Communications (CWSC) to deliver a TV White Space (TVWS) pilot in Orkney. The project built upon previous work to test and validate the use of White Space techniques for connecting extreme rural locations and to explore whether a similar solution may be used on a wider scale to support The Scottish Government's world-class digital aspirations.

In many countries, including the UK, analogue television broadcasts have been, or are in the process of being, switched off and replaced by more spectrally efficient digital television transmissions, and the 'white spaces' that exist in the UHF TV band (470 MHz - 790 MHz in ITU Region 1) have good propagation and building penetration characteristics. This potentially makes them suitable for use in rural broadband applications, where transmission links may be several kilometres in length and may involve challenging terrain such as hills, foliage, and water.

A number of spectrum regulators, notably the US regulator (FCC) and the UK regulator (Ofcom), have made certain parts of the TV band available for use on a shared and licence-exempt basis. This represents an interesting and novel development in the management of spectrum, as it involves licence-exempt transmissions being interleaved with those of licensed users such as TV broadcasters.

This 'dynamic shared access' approach represents an entirely new way of managing spectrum, and has been embraced by Ofcom as part of its spectrum management strategy, not only for spectrum in the TV band but also for spectrum in other bands where appropriate.[1] It is also widely recognized that dynamic spectrum access will form a key component of emerging 5G communication networks.

To deliver the project in Orkney, CWSC worked with a number of partners and suppliers, notably Cloudnet IT Solutions Ltd, an Orkney-based ISP who had prior experience of using White Space technology and who already had some wireless infrastructure (conventional microwave as well as some White Space) installed in Orkney.

The project was split into two distinct but related parts:

- Phase 2 Nomadic (P2N) – adding Wi-Fi connectivity to three Orkney ferries so that passengers (and crew) will be able to obtain access to the Internet while journeying on the ferries.
- Phase 2 Extended (P2E) – the setting up of communications links to a small number of fixed land-based premises in remote, difficult-to-reach locations which are and beyond the scope of current intervention initiatives.

The ferries now have useful Internet connectivity that was hitherto non-existent, and many users (passengers and crew) have found this very useful. Residents in the fixed premises have also found the connectivity useful, some of them even being able to start their own on-line businesses from home, which was not possible prior to the connectivity provided by the project.

The costs associated with building and running a network (whether it uses wireless technologies or other technologies) are numerous and diverse, and the commercial viability of networks in remote rural locations is highly sensitive to those costs due to the low population densities that usually exist in such areas. Each project therefore requires its own careful planning and costing activities in order to gain advance indications of CapEx and Opex costs.

[1] Ofcom: "Spectrum management strategy", 30th April 2014.

In summary, the Orkney TV White Space Pilot has successfully demonstrated the viability of using TV White Space radio equipment to enhance broadband coverage in hard-to-reach, remote locations, including not only fixed premises but also other 'locations' such as moving ferries. It has shown that TVWS has the potential to exceed the EC's definition of superfast broadband (30 Mbit/s or more), and is therefore aligned with the Scottish Government's commitment, under its 'R100' programme, to deliver superfast broadband access to 100% of premises in Scotland.

It is clear, therefore, that dynamic spectrum management will have an increasingly important role to play in the future management of spectrum, and we in Scotland are well-positioned to make a significant contribution to its development and deployment.

Building upon the Orkney TVWS pilot, the University of Strathclyde has driven the creation of a bid for Phase 1 of the DCMS 5G Testbeds & Trials programme[1], with a strong focus on rural connectivity. If the bid is successful, the project (titled '5G RuralFirst') will be an end-to-end testbed system comprising rural 5G testbed locations across the UK in Orkney, Somerset and Newport (Shropshire), linked to a 5G edge facility near Glasgow which will be connected to, and will complement, the 5G cores in Bristol and Surrey.

The 5G RuralFirst project consortium, which is led by Cisco and includes the BBC, BT, Microsoft, Faroese Telecom, Orkney-based CloudNet IT Solutions, DataVita, the University of Edinburgh, Heriot Watt University, and others, firmly believes that 5G must be more than simply 'better 4G', otherwise rural communities will continue to remain poorly connected as the business models and barriers to deployment in remote locations will essentially be no different from those of 4G and 3G, which have failed may rural locations in the UK. The opportunity for 5G connectivity will thus be clearly driven by new technologies and access to usable spectrum. And for spectrum we see the critical opportunity for a rural offering of a blend of licensed, licence-exempt, and shared; hence with a particular focus on dynamic spectrum and rural coverage, we aim to design and build successful testbeds and trials in rural areas that are 5G – 5G RuralFirst!

If our 5G RuralFirst bid is successful, the project consortium will consider opportunities for announcing it at the IEEE International 5G summit which will be held in Glasgow on 14th May 2018.

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/652263/DCMS_5G_Prospectus.pdf

Acknowledgements

The support and guidance received from the Scottish Government in the undertaking of this project is gratefully acknowledged.

Glossary Of Terms

ACS	Adjacent Channel Selectivity.
AGC	Automatic Gain Control.
AGL	Above Ground Level
AP	Access Point
BS	Base Station.
C/I	Ratio of Carrier power to Interference power.
COM	Commercial multiplex.
Coupling Gain/Loss	A measure of the extent to which electromagnetic energy radiated by a WSD antenna gets picked up by a DTT antenna. Coupling gain/loss is typically measured in decibels (dB).
CPE	Customer Premises Equipment.
CWSC	Centre for White Space Communications
dBm	Unit of power, measured in decibels relative to 1 milliwatt (mW).
dBµV/m	Unit of electric field strength, measured in decibels relative to 1 microvolt per metre (µV/m).
Downlink	Radio link from BS to CPE.
DTT	Digital Terrestrial Television.
DVB-T	Digital Video Broadcasting - Terrestrial. (European DTT standard, adopted by numerous countries worldwide.)
EIRP	Effective/Equivalent Isotropic Radiated Power – The power that an isotropic antenna would need to radiate in order to produce the same power as an actual antenna in its direction of maximum power transmission.
FCC	Federal Communications Commission (US regulator).
HP	Horizontal Polarization.
IP	Internet Protocol.
ITU	International Telecommunication Union.
LOS	Lone Of Sight
MAC	Medium Access Control – Mechanism by which a device's access to the radio link is controlled.
MIMO	Multiple Input, Multiple Output – The use of multiple antennas to improve communications performance.

NLOS	Non Line Of Sight
Ofcom	Office of Communication (UK regulator).
PHY	Physical layer – Mechanism by which signals are modulated and transmitted on a radio link.
PMSE	Programme Making & Special Events – e.g. wireless microphones and in-ear monitors used in theatres, sports venues, music festivals, etc.
POE	Power Over Ethernet.
PoP	Point of Presence
Protection Ratio	The minimum permitted ratio between a wanted DTT signal and an interfering signal for stable TV reception.
PSB	Public Service Broadcast.
RTT	Round-Trip Time – the time interval between a data packet being transmitted and a corresponding acknowledgement being received.
TCP	Transmission Control Protocol.
TDD	Time Division Duplex – Transmit and Receive signals are time division multiplexed in order to emulate full-duplex communication on a half-duplex physical channel.
TVWS	TV White Space – White spaces in the TV band (470-790 MHz for ITU Region 1).
UDP	User Datagram Protocol.
UHF	Ultra-High Frequency (300 MHz – 3 GHz).
UKPM	UK Planning Model.
Uplink	Radio link from CPE to BS.
UNESCO	United Nations Educational, Scientific, and Cultural Organization.
VoIP	Voice over IP – the transmission of speech over IP networks.
VP	Vertical Polarization.
White Spaces	Portions of radio spectrum which are not used by existing licensees at all times or in all locations.
WSD	White Space Device.

1 INTRODUCTION

In September 2015, the Scottish Government awarded a grant[1] to the University of Strathclyde's Centre for White Space Communications (CWSC) to deliver a TV White Space (TVWS) pilot in Orkney. The project built upon previous work to test and validate the use of White Space techniques for connecting extreme rural locations and to explore whether a similar solution may be used on a wider scale to support The Scottish Government's world-class digital aspirations.

The main aims/expected outcomes were:

- To demonstrate White Space technology in a rural environment using it as a backhaul technology to provide public Wi-Fi access;
- To test the reliability and performance of TVWS backhaul in a nomadic capacity where users will access services 'on the move' via the provision of ferry Wi-Fi hotspots;
- To gain an understanding of the costs associated with the delivery, operation, and maintenance of the supporting TVWS infrastructure;
- To assess the impact of the introduction of a ferry-based Wi-Fi service for the local community, visitors, and businesses;
- To test the commercial viability of TVWS as a solution for the provision of broadband services to extremely remote rural home- or office-based users with different requirements;
- To test the reliability and performance of TVWS technology as an alternative backhaul solution for the provision of broadband services;
- To gain an insight into the complexity, partnerships, resources, skills, and timelines required to deploy the TVWS infrastructure;
- To understand whether a similar solution could be used on a wider scale to support SG's World Class Digital aspirations.

This report describes the project activities and sets out some conclusions and recommendations on connecting remote rural communities. The report is structured as follows:

- Section 2 provides background and context, in terms of the current situation regarding broadband connectivity in rural areas and the benefits of using dynamic spectrum management techniques;
- Section 3 gives a high-level overview of the network, with a map of the overall network in Orkney;
- Section 3.1 discusses the CPE nodes (i.e. radio nodes installed at customer premises, which include three ferries);
- Section 3.2 discusses the infrastructure nodes, which are essentially basestations and/or backhaul nodes that require masts;
- Section 4 discusses network performance and user experience;
- Section 5 considers some of the financial aspects that are associated with deploying a wireless network on a commercial basis;
- Section 6 provides a summary and conclusion.

[1] Grant award letter dated 11th Sep 2015 and signed by University of Strathclyde on 16th Sep 2015.

2 Background and Context

In a recent presentation by Ofcom[1], it was recognized that while significant improvements have been made to fixed broadband and mobile coverage in Scotland, 37% of rural premises in Scotland still cannot get broadband faster than 10 Mbit/s. Figure 2-1 shows the UK's ten local authorities with the most premises unable to 10 Mbit/s. Five of them are in Scotland, with Orkney, Shetland, and the Hebrides occupying slots 2, 3, and 4, respectively.

Local authorities with the most premises unable to get 10Mbps	
Merthyr Tydfil	39%
Orkney Islands	34%
Shetland Islands	34%
Hebrides	29%
Ceredigion	29%
Kingston upon Hull	28%
Powys	26%
Argyll and Bute	26%
Fermanagh and Omagh	25%
Highlands	22%

Figure 2-1: Local authorities with the most premises unable to get 10 Mbit/s fixed broadband connectivity.

In many countries, including the UK, analogue television broadcasts have been, or are in the process of being, switched off and replaced by more spectrally efficient digital television transmissions, and the 'white spaces'[2] that exist in the UHF TV band (470 MHz - 790 MHz in ITU Region 1) have good propagation and building penetration characteristics.[3] This potentially makes them suitable for use in rural broadband applications, where transmission links may be several kilometres in length and may involve challenging terrain such as hills, foliage, and water.

A number of spectrum regulators, notably the US regulator (FCC) and the UK regulator (Ofcom), have made certain parts of the TV band available for use on a shared and licence-exempt basis. This represents an interesting and novel development in the management of spectrum, as it involves licence-exempt transmissions being interleaved with those of licensed users such as TV broadcasters.

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[1] "Implementing 'Digital Scotland' - broadband, mobile and infrastructure", Scotland Policy Conferences, 26th October 2016.

[2] 'White Spaces' are portions of radio spectrum which are not used by existing licensees at all times or in all locations. With demand for wireless connectivity increasing, the dynamic exploitation of white space is an attractive way of making more efficient use of radio spectrum.

[3] Radio signals at 470-790 MHz are better able to diffract over hills and penetrate objects such as foliage than signals at higher frequencies such as 2.4 GHz or 5.8 GHz.

Several other regulators around the world are actively considering similar spectrum sharing approaches.

Allowing licence-exempt devices to interleave their transmissions with those of licensed users does, however, present challenges in ensuring that the licence-exempt transmissions will not adversely interfere with the licensed transmissions. The approaches adopted by the FCC and Ofcom differ slightly, but both involve the use of a regulator-approved database which White Space Devices (WSDs) must consult before being allowed to access the spectrum. Figure 2-2 illustrates the concept.

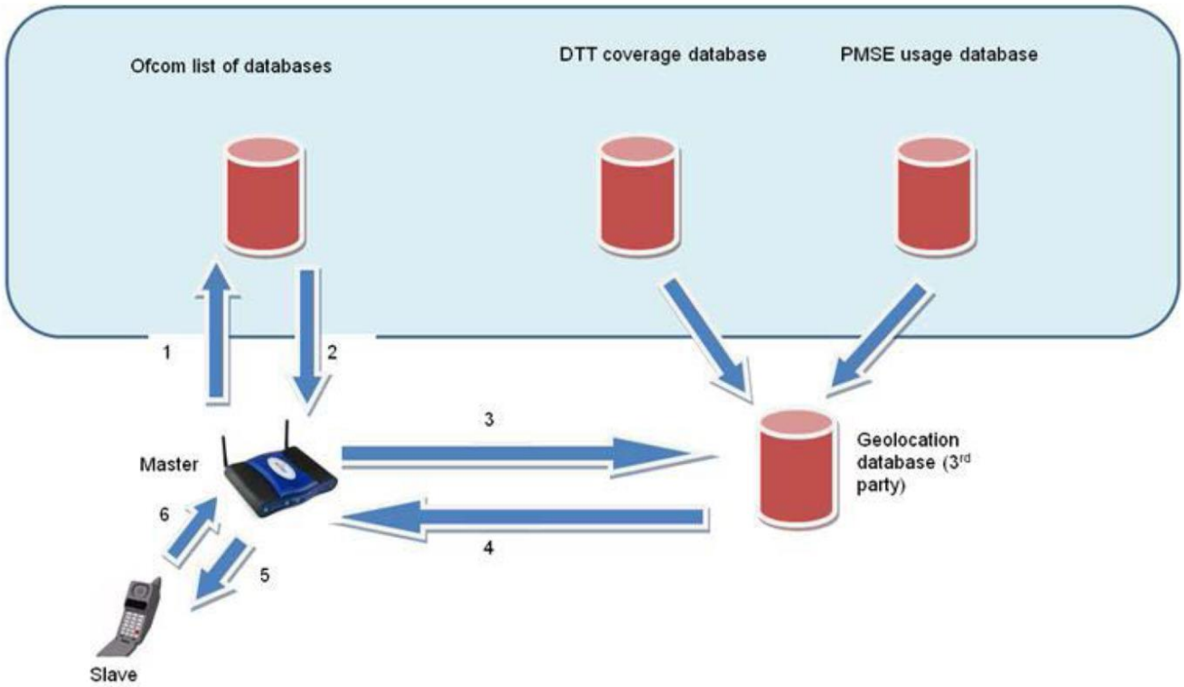


Figure 2-2: High-level overview of White Space access framework[1].

This 'dynamic shared access' approach represents an entirely new way of managing spectrum, and has been embraced by Ofcom as part of its spectrum management strategy, not only for spectrum in the TV band but also for spectrum in other bands where appropriate.[2] It is also widely recognized that dynamic spectrum access will form a key component of emerging 5G communication networks.

The University of Strathclyde's Centre for White Space Communications (CWSC) was established in March 2011, and has been working alongside industry and government to investigate the technical issues and develop solutions for dynamic spectrum sharing. Two prior projects of particular relevance are:

- The Isle of Bute White Space Trial[3] – a six-partner project supported by the Technology Strategy Board, and the UK's first White Space trial. The project consortium (which included BT and BBC) set up a test/demonstrator network on the Isle of Bute in 2011, and successfully demonstrated the technical feasibility of using White Space spectrum without

[1] Source: Ofcom Statement, "Implementing TV White Spaces", 12th February 2015.

[2] Ofcom: "Spectrum management strategy", 30th April 2014.

[3] http://www.wirelesswhitespace.org/projects/white-space-trial-on-the-isle-of-bute/

causing undue interference to TV reception. Results were fed into Ofcom and European spectrum policy working groups.

- The Glasgow TVWS Pilot[1] – a Scottish Government supported project which involved CWSC building a testbed White Space network on its city centre campus in 2014, and using it to help Ofcom to validate its proposed regulatory framework which went live at the end of 2015.

The pilot White Space network in Orkney builds upon CWSC's knowledge and expertise in wireless communications, dynamic spectrum management, and rural broadband. The network has provided connectivity to three inter-island ferries and six fixed premises in remote, hard-to-reach locations.

To deliver the project, CWSC worked with a number of partners and suppliers, notably Cloudnet IT Solutions Ltd, an Orkney-based ISP who had prior experience of using White Space technology and who already had some wireless infrastructure (conventional microwave as well as some White Space) installed in Orkney.

The project was split into two distinct but related parts:

- Phase 2 Nomadic (P2N) – adding Wi-Fi connectivity to three Orkney ferries so that passengers (and crew) will be able to obtain access to the Internet while journeying on the ferries.
- Phase 2 Extended (P2E) – the setting up of communications links to a small number of fixed land-based premises in remote, difficult-to-reach locations which are and beyond the scope of current intervention initiatives.

2.1 Project Partners

The project has involved the following partners working in collaboration to fulfil the project's aims:

- **The University of Strathclyde** is a leading international technological university located in the heart of Glasgow. The University's Centre for White Space Communications has been actively engaged in research into innovative dynamic spectrum management techniques for more than five years, and was the lead partner in the Orkney project being reported on in this document.
- **CloudNet IT Solutions Ltd** is a wireless solutions provider based in Orkney. The company specializes in connectivity to hard-to-reach areas, and was the local partner on Orkney, with responsibility for installing the network infrastructure and operating it for the duration of the pilot.
- **Fairspectrum Oy**, based in Espoo, Finland, provides consultancy and radio spectrum management tools for wireless network designers and implementers. The company is an Ofcom-approved TV White Space geo-location database supplier for use in the UK, and the project has made use of Fairspectrum's database for TVWS access in Orkney.
- **6 Harmonics Inc.** is a Canadian TV White Space radio manufacturer. The project uses their GWS 3000 range of TVWS radio products.
- **BAE Systems** provides some of the world's most advanced, technology-led defence, aerospace, and security solutions, employing over 80,000 skilled personnel in more than 40 countries. BAE provided TVWS radio hardware for connectivity to three ferries in Orkney.

[1] http://www.wirelesswhitespace.org/projects/white-space-pilot-network-in-glasgow-phase-1/

- **Orkney Ferries** operates a fleet of 9 vessels serving 13 island destinations in Orkney, carrying over 82,000 vehicles and undertaking around 320,000 passenger journeys annually. Three of the company's ferries participated in the project and were connected using TVWS so that passengers and crew could access the Internet during their journeys.
- **Orkney Islands Council** has provided valuable assistance and guidance during the project, and has also made space available on its mast at Wideford Hill for the purposes of facilitating the project.
- **Scottish Futures Trust** is an infrastructure delivery company owned by Scottish Government, working with numerous public and private sector partners across many programmes. SFT was instrumental in defining and scoping the Orkney TVWS pilot and helping the University of Strathclyde to run the project.

3 NETWORK OVERVIEW

Figure 3-1 shows a high-level representation of the network.

Six fixed premises (depicted by green circles) and three ferries (depicted by green ovals) have TVWS CPE units installed on them. These TVWS CPEs connect to TVWS basestations installed at land-based infrastructure nodes (depicted by blue circles).

The network has a main infrastructure node at Wideford Hill near Kirkwall, and all other infrastructure nodes are connected to the Wideford Hill node via Point-to-Point (P2P) microwave links. In addition, Wideford Hill also has its own TVWS basestations, which provide White Space connectivity to the ferries and to three fixed premises.

Internet access for the network is achieved via a Point of Presence (PoP) which exists at Ayre of Cara and is operated by Faroese Telecom. This connects to the UK mainland via the SHEFA-2 sub-sea fibre-optic cable, and achieves Internet access from Telehouse in London.

The network's main radio node at Wideford Hill near Kirkwall, and this is connected to the PoP via a Point-to-Point (P2P) microwave link, through which all of the network's Internet traffic flows.

On each of the ferries, the TVWS CPE is connected to a Wi-Fi Access Points (APs) installed in the passenger lounge, and passengers connect using their Wi-Fi-enabled smartphones, laptops, tablets, etc.

The TVWS CPEs at each of the fixed premises connect to a standard in-home Wi-Fi router using Cat5e Ethernet cable, and users can connect to the network using smart phones, tablets, laptops, desktop PCs, smart TVs etc.

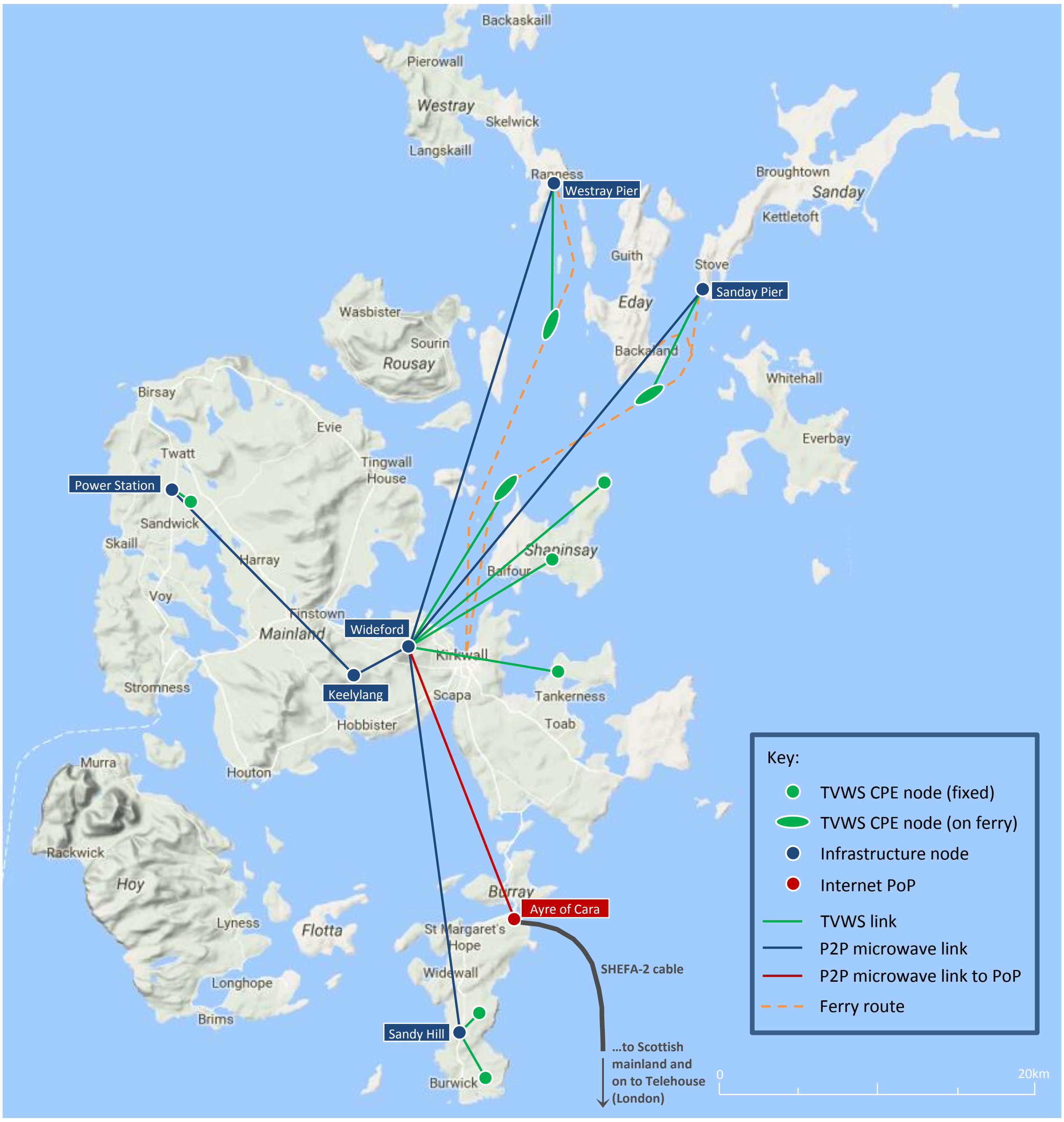


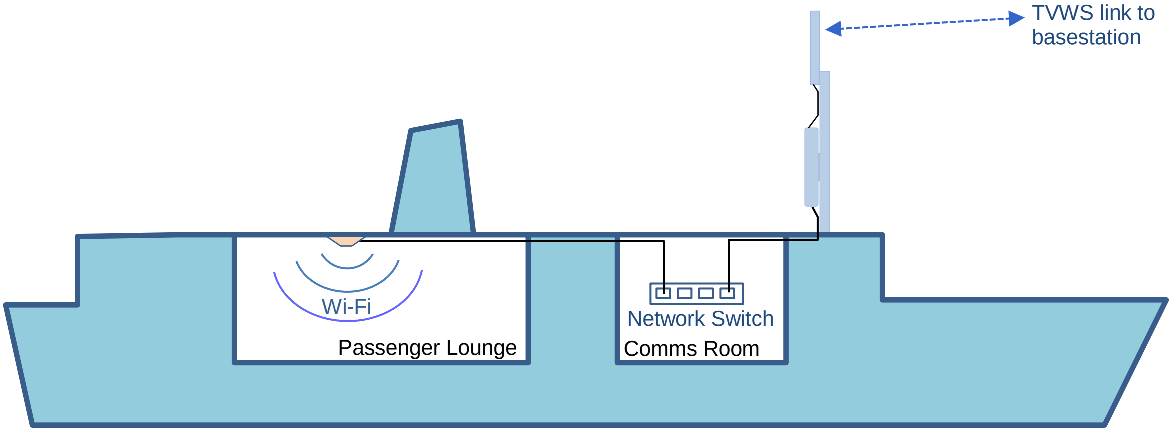
Figure 3-1: High-level network diagram.

3.1 CPE Nodes

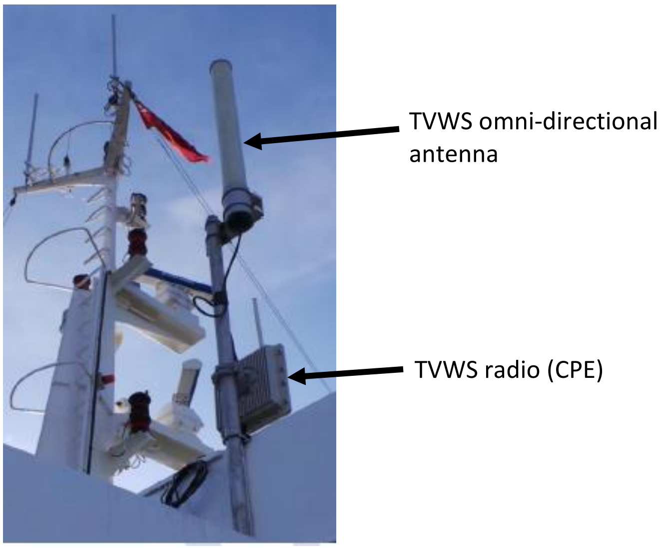
The TVWS CPEs installed at the fixed premises and on the ferries comprise essentially the same equipment and set-up requirements.

3.1.1 Ferries (P2N)

Figure 3-2(a) shows a simplified graphic illustration of the Wi-Fi set-up in the passenger lounge and its connection to the TVWS radio TVWS CPE installed on one of the ferries. Figure 3-2(b) shows the TVWS actual radio and antenna. They are pole-mounted, and since the radio can be powered via Power Over Ethernet (POE), a single Cat5e cable is sufficient to carry data and power to the radio from a POE-enabled network switch located in a comms room below deck. An omni-directional antenna is used because the ferry's orientation varies and can, in theory, have any bearing angle between 0° and 360°.



(a)



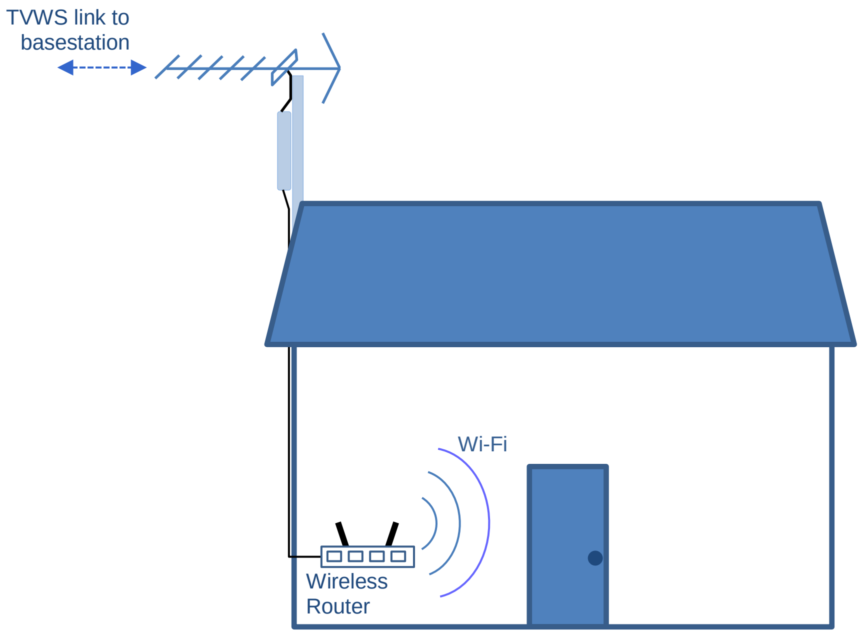
(b)

Figure 3-2: (a) Simplified graphic illustration of Wi-Fi set-up in passenger lounge and connection to TVWS radio; (b) TVWS CPE and omni-directional antenna mounted on ferry.

3.1.2 Fixed Premises (P2E)

Figure 3-3(a) shows a simplified graphic illustration of the in-home Wi-Fi set-up and connection to the TVWS CPE, and Figure 3-3(b) shows actual TVWS CPE installations at fixed premise locations. The set-up is very similar to that of the ferries, the main difference being the use of a directional aerial rather than an omni-directional one, since the orientation of the building never changes and the direction of the basestation is therefore fixed and known.

One of the TVWS aerials, shown on the bottom-left of Figure 3-3(b), is internally mounted because external mounting was unviable for a number of reasons. Nevertheless, the TVWS radios were still able to establish connectivity between basestation and CPE, which would have been very difficult, if not impossible, with conventional microwave radios operating in the 2.4 GHz or 5 GHz bands.



(a)

(b)

Figure 3-3: (a) Simplified graphic illustration of in-home Wi-Fi set-up and connection to TVWS radio; (b) TVWS CPE installation at fixed premises.

3.2 Infrastructure Nodes

The infrastructure nodes host the TVWS basestation units and other microwave radios that are required for the provision of wireless backhaul to the Internet PoP at Ayre of Cara. They typically comprise a mast on which the TVWS and microwave radios are mounted (typically at a height of around 10-15m AGL). The details of each infrastructure node are given in Appendix A.

4 Network Performance and User Experience

Throughout the project, users have been making use of the connectivity for a variety of purposes. Data throughput on the network depends on several factors, such as transmit power levels, antenna gains, path loss, signal reflections, etc., as well as the core performance capabilities of the radio equipment.

The TVWS radios used in the project are GWS3000 series radios from 6 Harmonics, Inc. Some of these are older versions which operate in a single 8 MHz-wide TV channel, while others are newer models which are capable of operating over two TV channels, i.e. 16 MHz of bandwidth. Laboratory tests have shown that the older, single-channel models are capable of supporting up to about 10 Mbit/s data throughput under good channel conditions, while the newer, dual-channel models are capable of supporting up to 40 Mbit/s.

Performance in the real network depends on the specific details of the radio links, and also on the extent to which radio bandwidth is being shared; for example, if two or more CPEs are served from a single basestation, they will share the basestation's overall data throughput capability.

4.1.1 Ferries (P2N)

Measurements made on the ferry links show that data rates tend to be in the range of about 5-10 Mbit/s, depending on where the ferry is located. Figure 4-1, for example, shows data throughput rates measured on board MV Varagen at various points on its route from Kirkwall to Sanday.

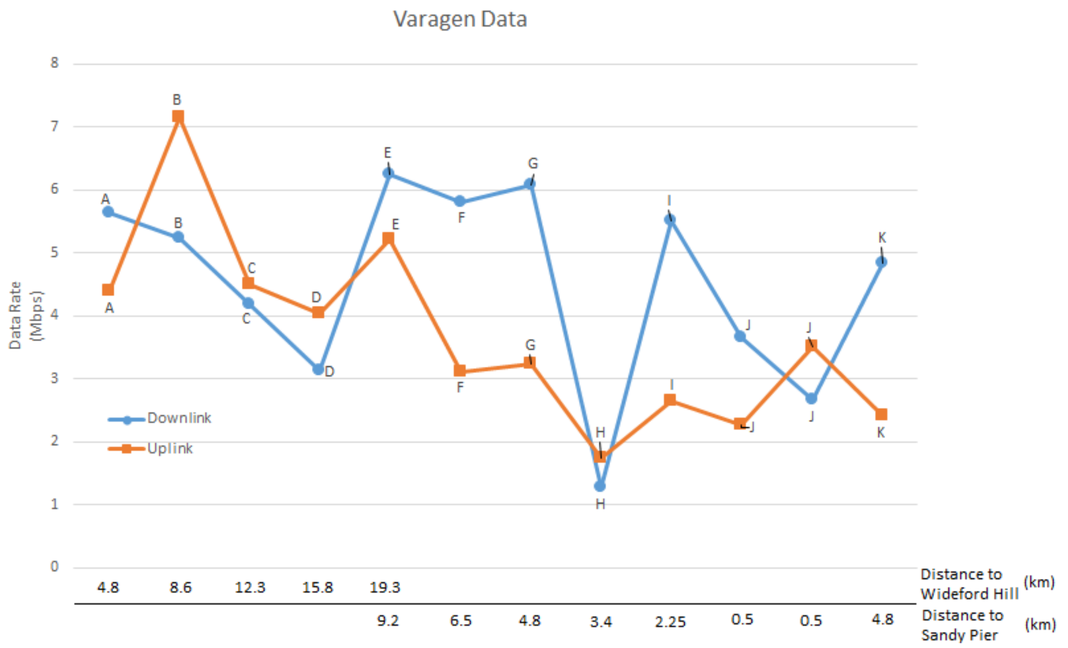


Figure 4-1: Data throughput measured on MV Varagen at various points along the ferry route from Kirkwall to Sanday.

It is worth noting that the TVWS radios installed on the ferries are not the latest versions, and as such, they are capable of a maximum data transfer rate of around 10 Mbps under ideal conditions, with a typical rate on the ferry routes being somewhere in the region of 5 Mbps. Nevertheless, this has provided useful Internet connectivity that was hitherto non-existent, and many users have found this very useful.

The latest TVWS radios will typically perform at double the data rate of the ones currently deployed on the ferries, and they are also capable of bonding more than one TV channel, which results in yet further increases in the data throughput. By extrapolation, it is reasonable to infer that these latest radios would, if installed on the ferries in place if the existing older versions, be able to support around 10-12 Mbps using a single TV channel, and around 20-24 Mbps if two TV channels were bonded.

Future TVWS radios are expected to be able to make use of up to four bonded TV channels, which suggests that up to 40-50 Mbit/s ferry connections could be achievable.

Since connectivity was installed on the ferries in the summer of 2016, usage has been measured in order to build a picture of client-side demand. Figure 4-2 shows the numbers of connected client devices on a daily basis over a period of one month. As can be seen, some 70-80 devices typically connect each day, with more than 100 devices connecting on some days.

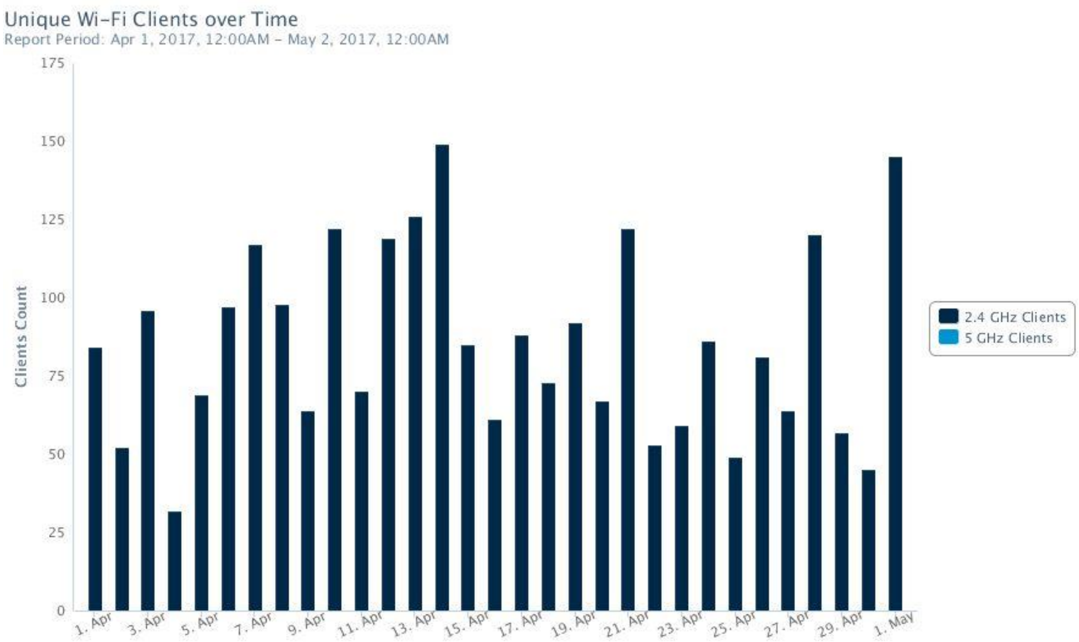


Figure 4-2: Client devices connected to ferry access points.

When accessing the Internet on the ferries, passengers were invited to participate in a survey which asks various questions aimed at understanding the user profiles and attitudes towards Internet connectivity on the ferries. Almost 400 people engaged in the survey, the key findings of which may be summarized as follows:

- Email and social media are the main applications that people use while travelling on the ferries. Other applications include on-line shopping, paying bills, homework/studying, playing games, and playing music.
- The vast majority of users (more than 98%) have stated that the service has been useful, with 78% citing it as being 'extremely useful'.

Figures 4-3 to 4-6 show the results of four particular questions that were asked in the survey. On the whole, passengers are very satisfied with the Internet connectivity obtainable on the ferries. Some passengers did, however, cite stability issues, although it's not clear whether they were trying to connect during a maintenance period or when the ferry was in a location of low signal. Most have stated that they would expect connectivity to be provided free of charge or as part of the ferry fare rather than paying for it separately or on a per-use basis.

Passengers who participated in the survey were also invited to provide comments where appropriate. Some received comments include:

"I can do my work whilst travelling on the boat. It is quality time to catchup with work whilst I travel.. Perfect!!"

"It has been really useful having internet access on the boat. Im currently studying for a degree so internet access is essential, the ferry is a good place to get a good hour or more uninterrupted work done."

"Extremely satisfied. I can do work, catch-up with notes etc and not waste time whilst travelling and having to catch-up when back in the office.. well done CloudNet. and Orkney Ferries.....About time!!!! Don't lose this service...."

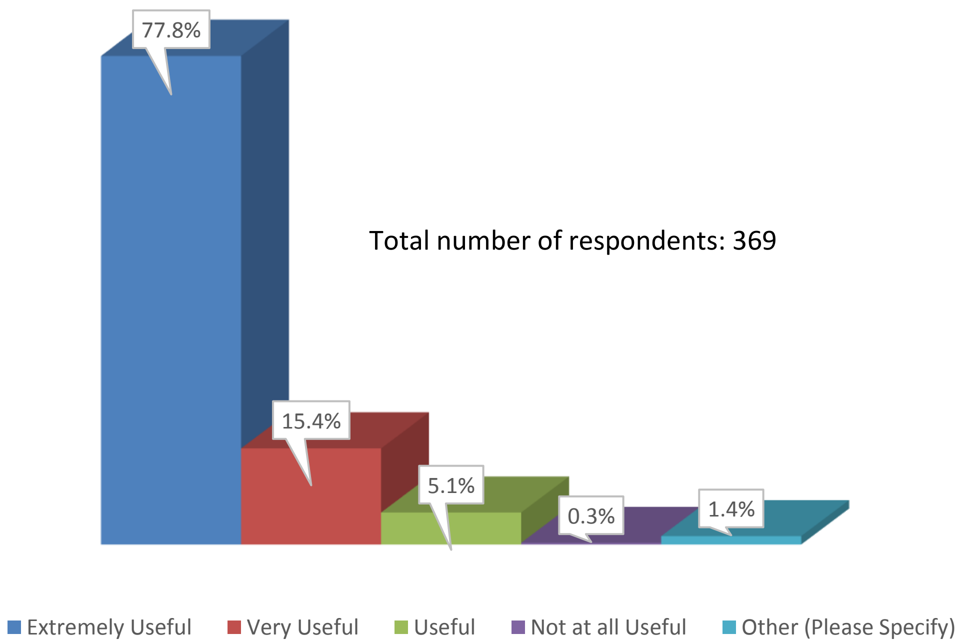


Figure 4-3: How useful have you found having access to Wi-Fi on the ferry?

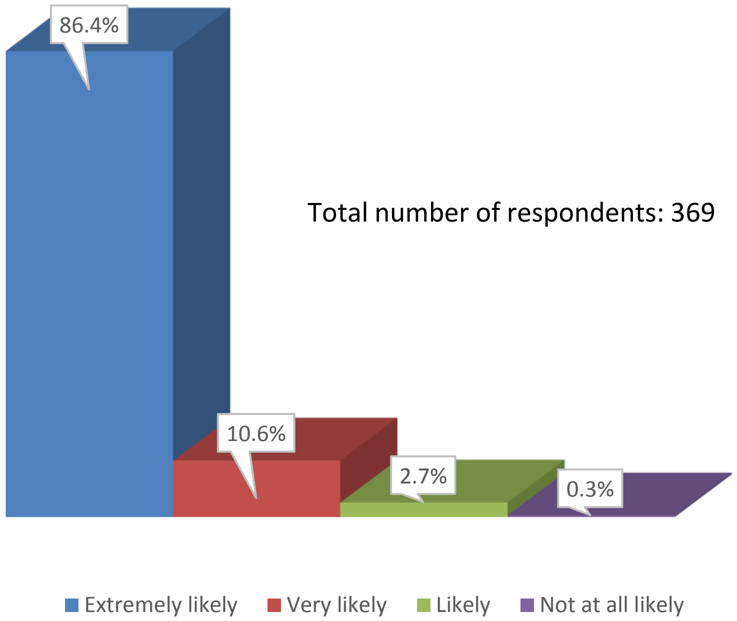


Figure 4-4: How likely are you to use the Wi-Fi access when you next travel on the ferry?

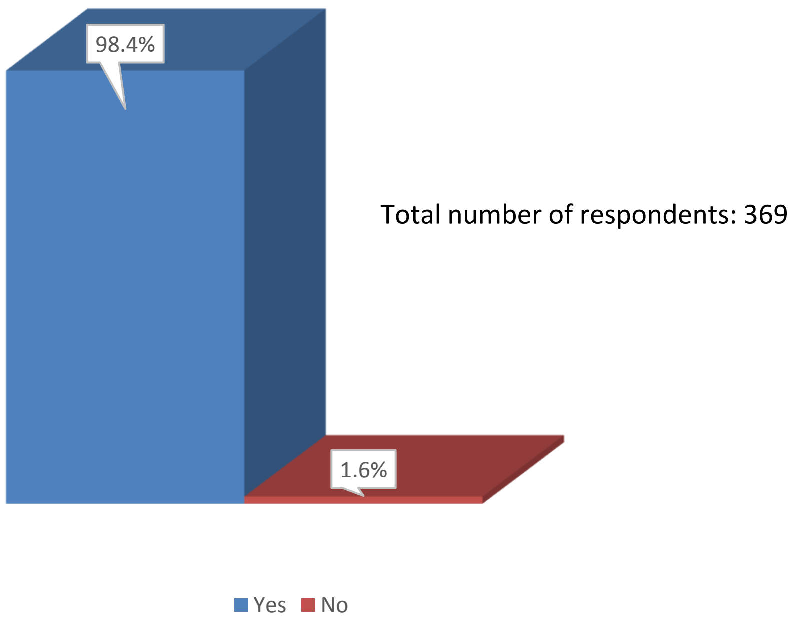


Figure 4-5: With the trial coming to an end would you wish to see public Wi-Fi continue?

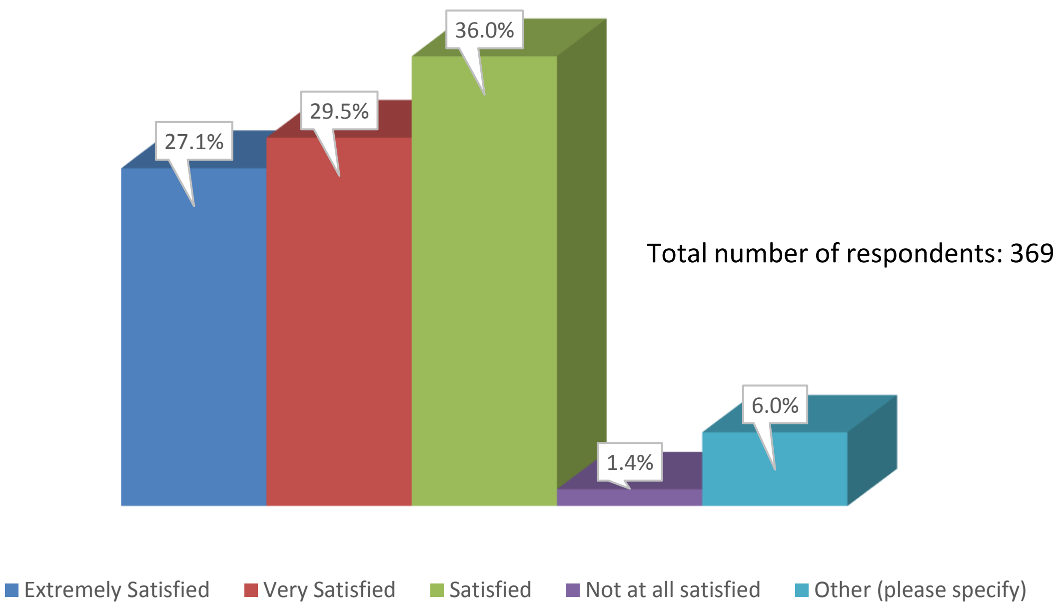


Figure 4-6: How satisfied are you with the reliability and speed of the WiFi?

The crew has also found the connectivity useful:

> *"The system works well, and its range is better than anything we have ever had or used to. We notice when the system goes off, because it's normally when we need to get weather reports, or, or need to report technical problems or to send/receive email from the office. It's like when you are given something then it's taken away you miss it.!"*
>
> *…Captain of MV Thorfinn*

> *"This new system is must better and faster than before. We can use the system when traveling and we have never been able to as a crew before."*
>
> *…Ships' Crew*

4.1.2 Fixed Premises (P2E)

Residents in the fixed premises have been using the network mainly for general Internet access from the home. In some cases, this has facilitated the set-up of home businesses which were not possible without the connectivity provided by the network. One resident, for example, was a language translator, and the Internet connectivity allowed her to receive and deliver work electronically and interact with her clients more effectively…

> *"Being a translator I had to download footage to translate and then upload again. This often took 2-3 days to download before I could start working on the scripts. The new system changed this, improving both upload and download speeds, making my work more efficient. It increased my productivity. Having a good rural broadband solution is necessary in today's society."*

In another case, the householder's son was able to start a home-based digital media company which would not have been possible without Internet connectivity…

"When TVWS was provided, it opened up the opportunities for my family to a whole new life. It gave my son the chance to start his own business doing digital media and film making. He now is able to interact across the globe with other similar people. Having this system installed kept the boys from moving out and living in Kirkwall, keeping the rural communities alive. As a councillor this was an active discussion point in the chamber and debates about rural connectivity and how to overcome digital inclusion and sustaining rural economies from decreasing. This system helps to keep our islands and their kids on these islands."

Of course, it's not just householders who require good connectivity. The farming industry is becoming more and more reliant on connectivity on and off the farm….

"As a farmer, we need more and more reliance on broadband to carry out our work. It not only allowed me to be out tending the farm but also provided means of monitoring the cattle in the byres. I could work out in the fields yet be in contact with the farm. So much so, I could be anywhere and log onto the farm camera system to look at the animals in the byres which allowed me to be more productive around the farm, and in calving time know how the beasts were doing, day or night."

Interestingly, the TVWS connectivity has also been used by Faroese Telecom to monitor shipping in the area where the SHEFA sub-sea fibre link exists. Conventional broadband from the telephone exchange wasn't able to provide enough bandwidth…

"SHEFA uses a radar system in Orkney to monitor and log ship traffic around the sub-sea fibre which links the Faroe Islands to London via Orkney and Shetland. The TV Whitespace system increased bandwidth to Radar to allow us to do this and to be able to record data of shipping traffic. The broadband system was too far from the exchange to provide Faroe Telecoms with the necessary data to actively monitor the network."

It is important to appreciate that achievable data rates depend on various factors associated with the radios and radio path properties. Each radio path is unique, and for any particular link from basestation to customer premises, the radio propagation characteristics – and hence the data throughput performance – are also unique.

Having said that, data throughput rates of up to 30 Mbit/s have been achieved at certain fixed premises with favourable radio path parameters and where the latest generation of TVWS radios (which are capable of using two bonded TV channels) have been installed. For older generation radios, data rates of around 10 Mbit/s have been achieved, again depending on radio path parameters. In the near future, it is expected that TVWS radios capable of using four bonded TV channels will become available, in which case data rates of up to 60 Mbit/s will be possible.

5 FINANCIAL CONSIDERATIONS

The project has been a research project and, as such, it has provided trialists with connectivity free of charge. However, as well as investigating the technical viability of using TVWS for connectivity in hard-to-reach rural areas, we have attempted to summarize some of the cost-related considerations that would need to be addressed in a commercial setting.

5.1 Capital Costs (CapEx)

Capital costs include:

- Cost of Radio Equipment
  - TVWS radios, Microwave radios, Aerials, Mounting brackets and accessories, Installation costs
- Cost of Infrastructure Nodes
  - Site access fees, Site preparation, Mast purchase, Mast installation and commissioning
- OSS/BSS set-up costs
  - Purchase of OSS/BSS, hosting/server costs

5.1.1 Radio Equipment

Radio equipment costs comprise TVWS basestations and microwave radios (if needed), along with associated antennas and accessories. TVWS radios are still relatively expensive as the technology is still relatively new. However, prices have been steadily decreasing over the past few years, and provided the market develops and grows, this trend is expected to continue. At present, a TVWS basestation with antenna and accessories typically costs about £4,000 and is capable of serving 4-6 CPEs.

Installing radios on towers requires qualified tower climbers, and Health & Safety rules require that there be at least two of them for each climb.

5.1.2 Infrastructure Nodes

The main costs associated with the land-based infrastructure relate to site agreements and mast construction. Each site is unique, however, and terms and conditions (e.g. site rental fees) for using a particular site depend on negotiations with the site owner. Where a mast already exists on a site, it may be possible to simply rent space on the mast; otherwise it will be necessary to purchase a suitable mast and carry out civil works to erect it. The costs associated with commissioning each site are therefore somewhat variable.

For example, our project's basestation site at Keelylang required an 18m mast to be erected. Civil works were required in order to level the ground and lay a concrete base and plinth, and to install drainage and a vehicular access gate. The mast itself had to be procured and installed, and an electricity supply had to be installed at the site. By contrast, the basestation site at Wideford hill makes use of an existing mast owned by Orkney Islands Council, and access was provided by the Council free of charge as the project was a research project.

5.1.3 OSS/BSS Set-Up Costs

Any commercial network requires OSS[1] and BSS[2] capability, regardless of whether it uses TVWS technology or not. Capital costs associated with this will include the purchase and configuration of the OSS/BSS software itself and hosting costs in a data centre. Depending on an ISP's needs and preferences, it may be preferable to rent server space from a commercial virtual server provider, which will eliminate the need for the ISP to operate its own servers in its own data centre. Some companies are even offering the entire OSS/BSS function as a service which gets paid for on a time-based or per-use basis, thereby eliminating the need for the ISP to purchase and operate its own OSS/BSS platform.

The best approach to take will depend on a particular ISP's needs and preferences. If the 'OSS/BSS as a service' approach is taken, the capital costs will be minimal (perhaps even zero), as all of the costs will be operational. However, the ISP will presumably need to be suitably satisfied that the OSS/BSS provider is capable of providing (and guaranteeing) appropriate levels of service in order to ensure that the ISP's guarantees to its own customers can be maintained. The ISP will also need to be suitably satisfied that the BSS service provider is able to comply with relevant data protection requirements.

5.2 Operating Costs (OpEx)

Once the network is installed, ongoing operational costs mainly comprise:

- Network maintenance costs
  - Inspection and maintenance (staffing costs as well as materials costs)
- OSS/BSS running costs
  - Recurring costs of OSS/BSS (e.g. data centre hosting fees)
  - Staffing costs (e.g. telephone helpline, office admin costs)
- Rental fees for sites and masts
- Licence fees for radio spectrum
- Backhaul costs
- IP transit costs

Many of the above costs will depend on the specific business structure the operating models that have been chosen. For example, staff costs will depend on how many staff are employed or allocated to a particular function, which, in turn, may depend on factors such as geographic coverage and desired service levels being achieved. Rental fees for sites and masts will depend on whether these have been negotiated as typical commercial agreements or have benefited from some 'goodwill' from members of the local community, such as a farmer agreeing to a corner of his field being used to site a mast without any rental payments being required, perhaps in turn for free broadband connectivity for his farmhouse. OSS/BSS running costs will depend on the specifics of the approach that has been adopted and the solution that has been implemented.

[1] OSS – Operations Support System. A toolset which facilitates network management and configuration as well as fault management, etc. May be 'cloud' based with server and web interface allowing authorized access from any location.

[2] BSS – Business Support System. A toolset which facilitates business processes such as customer billing, dealing with new customer requests, etc. Usually integrated with the OSS to a large extent to allow effective inter-working between OSS and BSS.

5.3 Summary

The costs associated with building and running a network are clearly numerous and diverse, and the commercial viability of networks in remote rural locations is highly sensitive to those costs due to the low population densities that usually exist in such areas. Each project therefore requires its own careful planning and costing activities in order to gain advance indications of CapEx and Opex costs.

6 Summary & Conclusion

The Orkney TV White Space Pilot has successfully demonstrated the viability of using TV White Space radio equipment to enhance broadband coverage in hard-to-reach, remote locations, including not only fixed premises but also other 'locations' such as moving ferries. It has shown that TVWS has the potential to exceed the EC's definition of superfast broadband (30 Mbit/s or more), and is therefore aligned with the Scottish Government's commitment, under its 'R100' programme, to deliver superfast broadband access to 100% of premises in Scotland.

The technology requires backhaul connectivity and infrastructure in the form of masts/towers upon which TVWS basestations can be mounted, and the costs of these need to be carefully considered in any business plan that aims to deliver broadband connectivity to a particular community or set of clients. Those costs are dependent on a number of factors and may vary over a large range from one deployment to another. A 'one size fits all' solution does not, therefore, exist, but White Space is nevertheless an extremely useful and valuable 'component' to have available for use in any solution.

In fact, our project in Orkney has, to one degree or another, demonstrated use of all six of the key 'pillars' required for effective connectivity, as identified by the Scottish Futures Trust and shown in Figure 6-1.

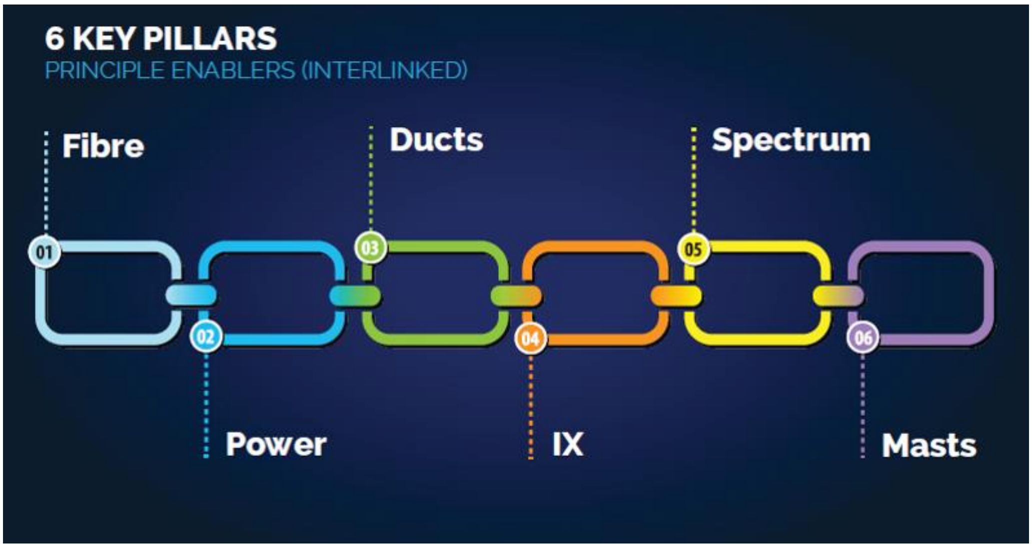


Figure 6-1: The six key pillars identified by the Scottish Futures Trust as essential for creating the environment for Scotland to be ready for new 5G connectivity. [1]

Specifically, we have in Orkney:

- Fibre connectivity (to Telehouse in London);
- Electrical power (including self-powered renewable-energy communications mast capability);
- Ducts (Faroese Telecom);

[1] "Taking The Connected Highway", *Scottish Futures Trust*, 2016. (https://www.scottishfuturestrust.org.uk/storage/uploads/Taking_the_Connected_Highway.pdf)

- Internet Exchange (Telehouse);
- Spectrum (licence-exempt spectrum such as White Space, as well as licensed spectrum via industry partners or via CWSC securing test licences as appropriate);
- Masts (existing masts plus experience of deploying new masts as needed).

A key feature of the use of White Space spectrum in the UK and several other countries is the dynamic spectrum management techniques that have been devised and incorporated into the regulations. This represents a brand new way of managing spectrum, and it presents new opportunities for maximizing the effective use of spectrum, in turn maximizing the value that can be derived from the use of spectrum.[1] It has been embraced by Ofcom in the UK as the way forward for spectrum management, not only in the TV band but in other bands, too.[2] Its value is also being specifically recognized for emerging 5G systems[3] and for the Citizens's Broadband Radio Service (CBRS) in the US[4].

It is clear, therefore, that dynamic spectrum management will have an increasingly important role to play in the future management of spectrum, and we in Scotland are well-positioned to make a significant contribution to its development and deployment.

6.1 Next Steps – 5G RuralFirst

Building upon the Orkney TVWS pilot, the University of Strathclyde has driven the creation of a bid for Phase 1 of the DCMS 5G Testbeds & Trials programme[5], with a strong focus on rural connectivity. If the bid is successful, the project (titled '5G RuralFirst') will be an end-to-end testbed system comprising rural 5G testbed locations across the UK in Orkney, Somerset and Newport (Shropshire), linked to a 5G edge facility near Glasgow which will be connected to, and will complement, the 5G cores in Bristol and Surrey. 5G RuralFirst will support trials of innovative technology, applications, and business models aimed at improving the overall potential of the UK's 5G eco-system to deliver cost-effective connectivity for a range of applications and usage scenarios in hard-to-reach rural locations. The general architecture of the testbed and trial is illustrated in Figure 6-2.

The project consortium, which is led by Cisco and includes the BBC, BT, Microsoft, Faroese Telecom, Orkney-based CloudNet IT Solutions, DataVita, the University of Edinburgh, Heriot Watt University, and others, firmly believes that 5G must be more than simply 'better 4G', otherwise rural communities will continue to remain poorly connected as the business models and barriers to deployment in remote locations will essentially be no different from those of 4G and 3G, which have failed may rural locations in the UK. The opportunity for 5G connectivity will thus be clearly driven by new technologies and access to usable spectrum. And for spectrum we see the critical opportunity for a rural offering of a blend of licensed, licence-exempt, and shared; hence with a particular focus on dynamic spectrum

[1] Quantifying the 'value' of spectrum is not easy, and depends on whether the emphasis is on measuring 'economic' value, 'social' value, or some other metric. Nevertheless, a report by Analysys Mason in 2013 suggests that the economic value of UK spectrum is £52 billion per annum.

[2] Ofcom: "Spectrum management strategy", 30th April 2014.

[3] According to Qualcomm (one of the world's leading mobile technology companies), access to shared/licence-exempt spectrum will expand 5G in multiple dimensions. (https://www.qualcomm.com/news/onq/2016/11/17/5g-spectrum-sharing-brings-new-innovations).

[4] CBRS is being pioneered in the US, operating in the 3.5 GHz band with dynamic spectrum sharing. (https://www.cbrsalliance.org/)

[5] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/652263/DCMS_5G_Prospectus.pdf

and rural coverage, we aim to design and build successful testbeds and trials in rural areas that are 5G – 5G RuralFirst!

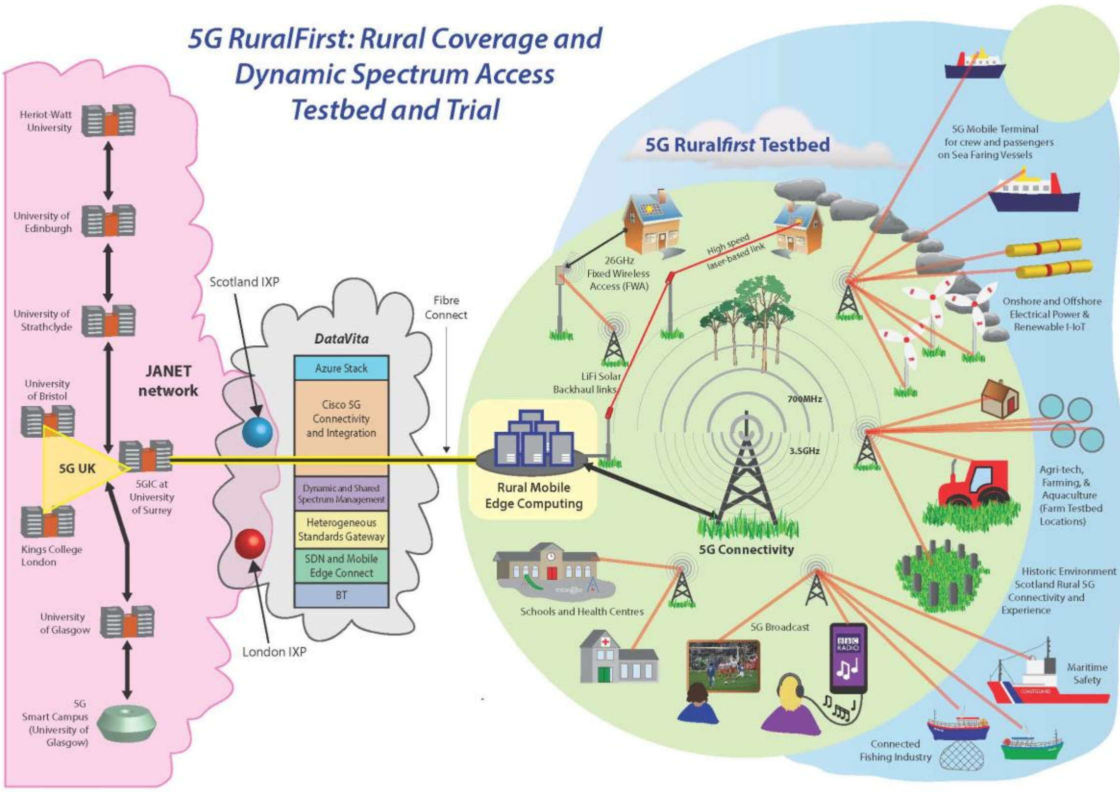


Figure 6-2: The 5G RuralFirst concept.

More detailed information on our 5G RuralFirst bid can be provided on request. If it is successful, the project consortium will consider opportunities for announcing it at the IEEE International 5G summit which will be held in Glasgow on 14th May 2018.[1]

[1] http://www.5gsummit.org/

Appendices

A INFRASTRUCTURE NODES

A.1 Internet PoP at Ayre of Cara

The Internet PoP at Ayre of Cara connects to the SHEFA-2 optical fibre cable owned operated by Shefa Ltd, a subsidiary of Faroese Telecom[1]. The SHEFA-2 cable runs from the Faroe Islands to mainland Scotland via Shetland and Orkney, and has PoPs in the Faroe Islands, Shetland, Orkney, Banff, Aberdeen, and London. Access to the Internet is provided via Telehouse in London. Figure A-1 shows a schematic representation of the PoP set-up.

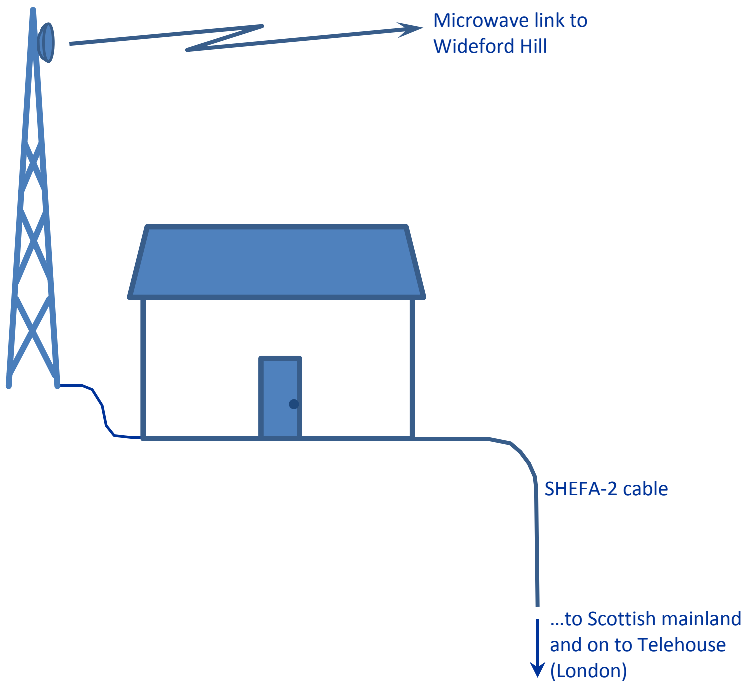


Figure A-1: Schematic representation of the PoP set-up at Ayre of Cara.

Figure A-2 shows the PoP building and its associated radio mast, as well as some of the equipment inside the building. Through a co-hosting arrangement, CloudNet has installed a microwave dish (shown halfway up the mast) plus associated networking equipment inside the building to provide the microwave link to Wideford Hill.

[1] http://www.shefa.fo/faroese-telecom/

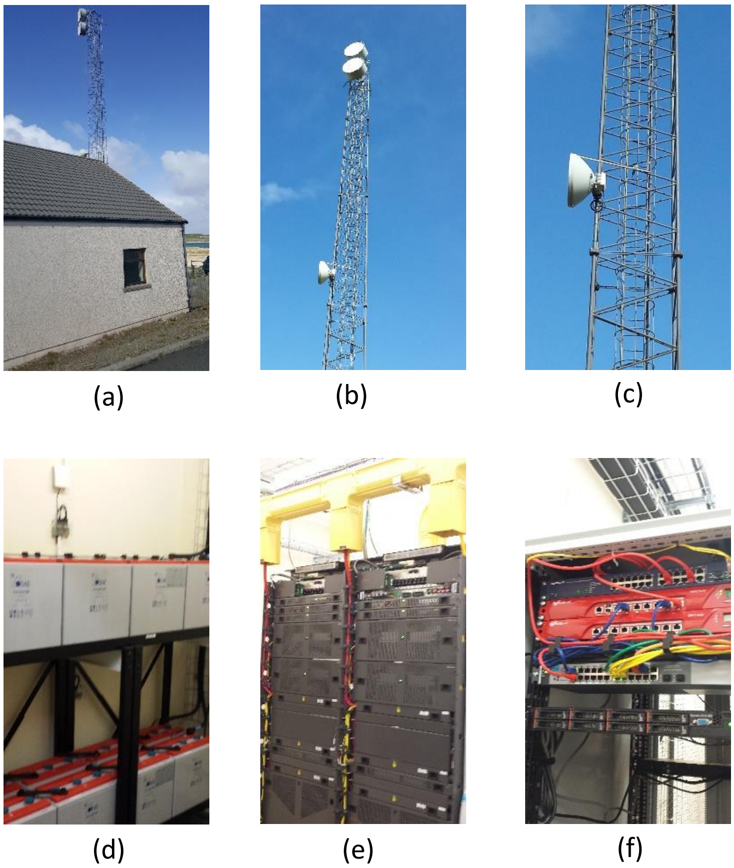


Figure A-2: Point of Presence (PoP) at Ayre of Cara.
(a) Comms building; (b) Comms tower; (c) Microwave link to Wideford Hill is provided by the dish halfway up the mast. (d) Battery back-up units maintain operational capability when electrical power supply is lost; (e) Optical transceivers; (f) Network switches.

A.2 Wideford Hill

The top of Wideford Hill sits at an altitude of approximately 220m above sea level, and has good Line-Of-Sight (LOS) to a number of other locations in Orkney, including some locations on other islands belonging to the Orkney archipelago. A multi-use radio tower exists at the top of Wideford Hill, and this has been used to form the main node in the project. The tower contains two TVWS basestations (multiplexed onto a single antenna) as well as microwave radios which form the Point-to-Point microwave links to Keelylang, Sandy Hill, Sanday Pier, Westray Pier, and Ayre of Cara, as previously illustrated in Figure 3-1.

Figure A-3 shows a schematic representation of the set-up at Wideford Hill, while Figure A-4 shows photographs of the tower and the views from the top of the hill.

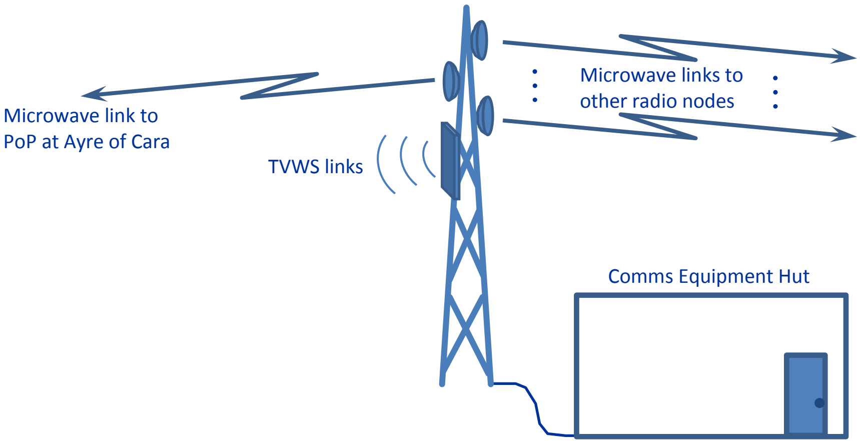


Figure A-3: Schematic representation of the radio node at Wideford Hill.

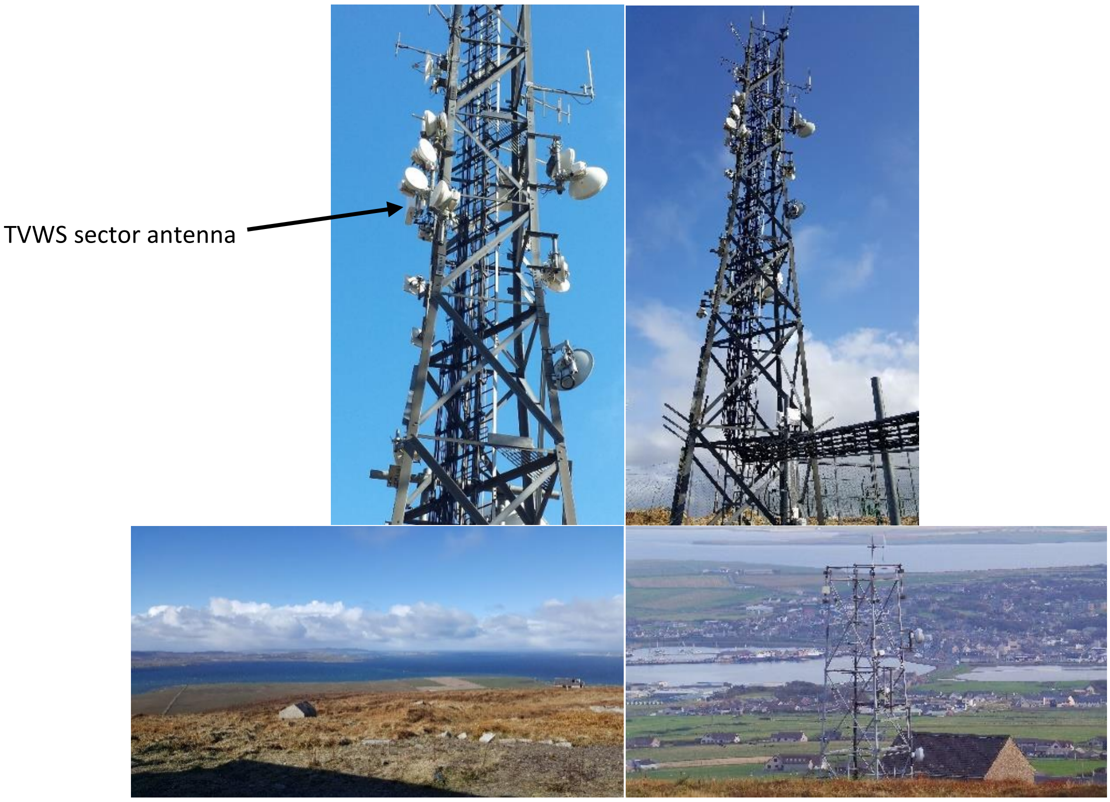


Figure A-4: Wideford Hill. The TVWS basestation sector antenna is just visible behind one of the microwave dishes.

A.3 Sandy Hill

Sandy Hill is located in South Ronaldsay and has a small (10m) mast installed next to a weather station from which electricity is obtained. The mast houses a microwave radio which forms the P2P backhaul link to Wideford Hill and a TVWS basestation which provides connectivity for two CPE locations in the surrounding area. The TVWS radio and associated equipment is housed in a small cabinet at the foot of the mast. Figure A-5 shows a schematic representation of the set-up at Sanday Hill, while Figure A-6 shows photographs of the equipment installed on-site.

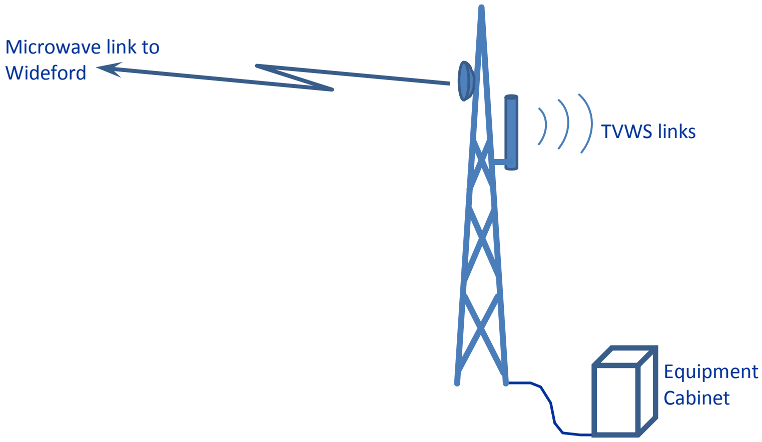


Figure A-5: Schematic representation of the radio node at Sandy Hill.

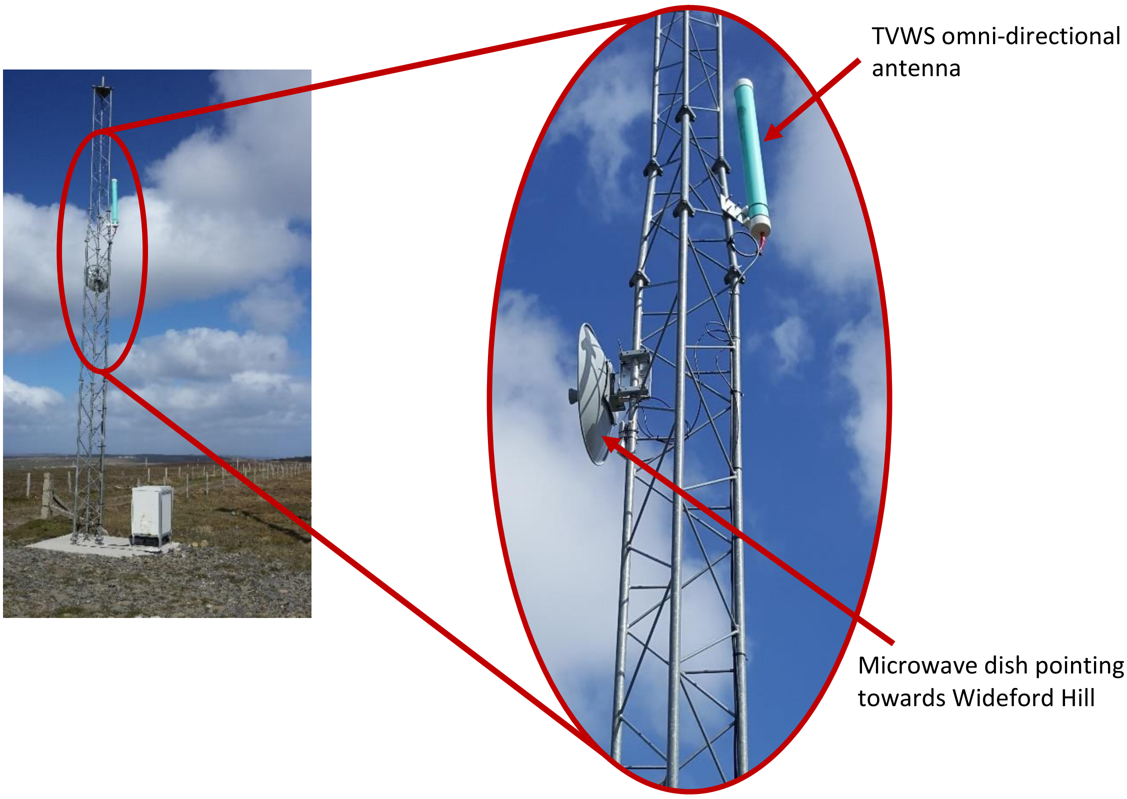


Figure A-6: Sandy Hill node. The microwave dish provides the P2P link to Wideford Hill, while the TVWS omni provides TVWS connectivity to two CPE locations. The TVWS basestation with associated equipment is housed in the cabinet at the foot of the mast.

A.4 Keelylang

Keelylang is a main transmitter site for digital TV (DTV) and digital radio (DAB). Its hilltop location gives it good coverage of the surrounding area. It is used in our network as a backhaul relay node, with P2P microwave links connecting the Wideford Hill node to the power station node situated in the west of mainland Orkney.

The site is owned and operated by Arqiva, and access to their masts involves considerable expensive and complexity. Therefore, we have instead installed our own 18m mast on the site, with electrical power provided by SSE.

Figure A-7 shows a schematic representation of the set-up at Keelylang, while Figure A-8 shows photographs of the site.

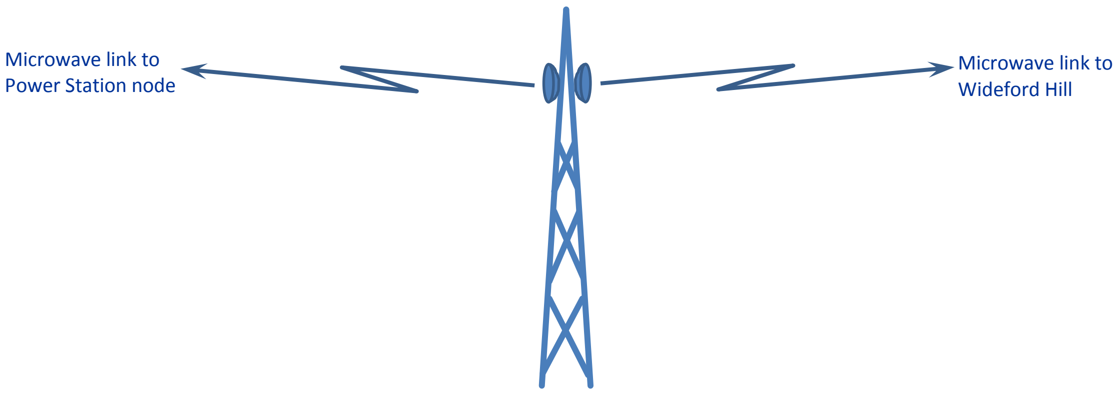
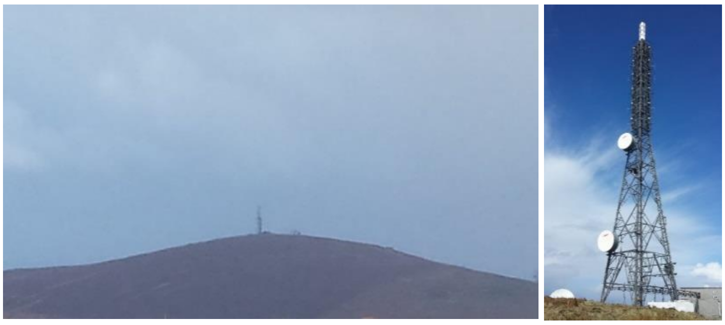


Figure A-7: Schematic representation of the relay node at Keelylang. (N.B. There are no TVWS radios installed here, although TVWS could be installed if required in the future.)



(a)

(b)

Figure A-8: Keelylang Hill – a main DTV and DAB transmitter site, serving most of Orkney and some northern parts of mainland Scotland.
(a) The hill with TV transmitter mast at summit;
(b) Our 18m mast installed adjacent to the TV transmitter facility.

A.5 Power Station

The Power Station node makes use of a disused power station, and provides coverage in an area towards the west of mainland Orkney. Figure A-9 shows a schematic representation of the Power Station node.

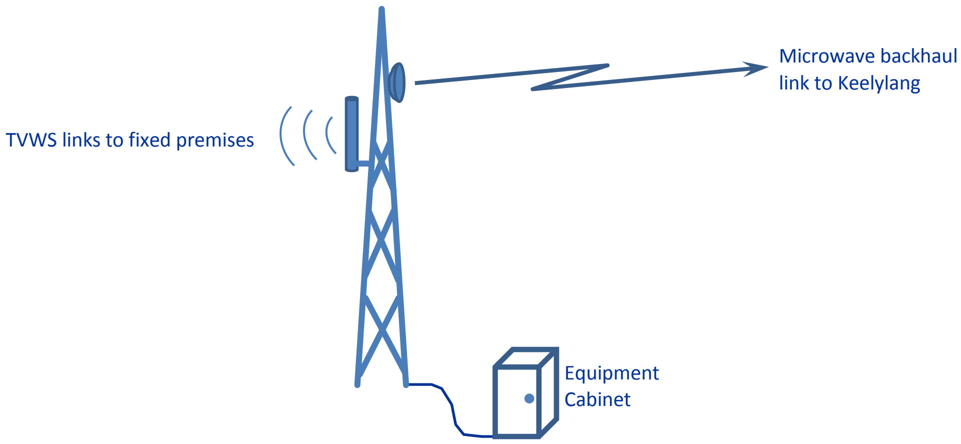


Figure A-9: Schematic representation of the radio node at disused power station.

A.6 Sanday Pier

The ferry terminal at Sanday Pier has a TVWS basestation installed on the existing ramp infrastructure, as shown in Figure A-10. The equipment comprises a TVWS basestation radio and omni-directional antenna for connecting to TVWS client radios on ferries, plus a microwave radio and dish antenna for the Point-to-Point (P2P) backhaul connection to Wideford Hill. Figure A-11 shows a schematic representation of the set-up.

Figure A-10: Sanday Pier basestation, with TVWS basestation for connectivity to ferries and microwave radio for P2P link to Wideford Hill.

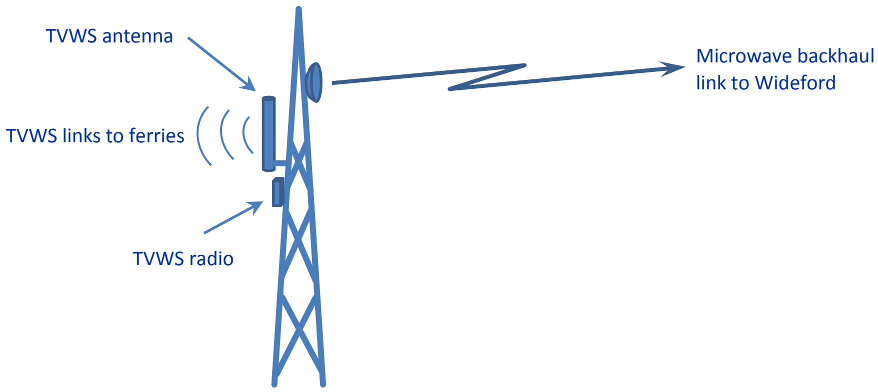


Figure A-11: Schematic representation of the radio node at Sanday Pier.

A.7 Westray Pier

The installation at Westray Pier is similar (in fact, almost identical) to that at Sanday Pier, i.e. a TVWS basestation for connectivity to ferries plus a microwave radio providing a point-to-point link to Wideford Hill. For the sake of completeness, a schematic representation of the set-up is shown in Figure A-12, which is identical to Figure A-11.

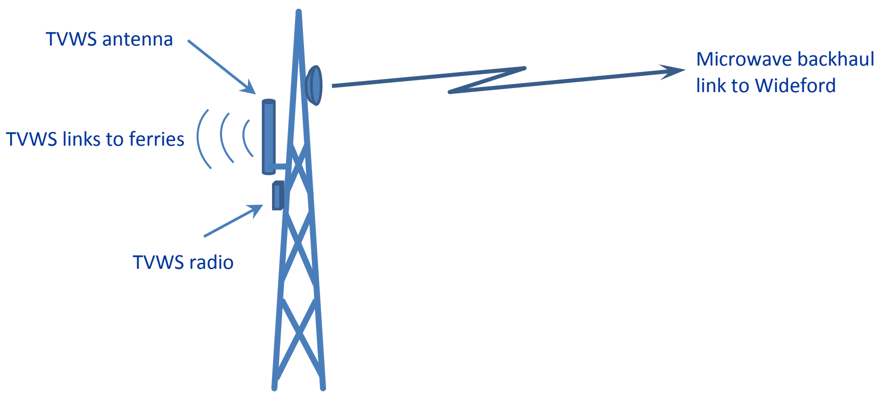


Figure A-12: Schematic representation of the radio node at Westray Pier.

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Document Version 1.01
12th February 2018