WHITE SPACE BROADBAND ON THE ISLE OF BUTE, SCOTLAND

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9.1 INTRODUCTION

In April 2011, a six-partner consortium, with support from the UK government's Technology Strategy Board, started work on a rural broadband trial network that would use white space radio spectrum to provide broadband connectivity to a small community on the south part of the Isle of Bute, Scotland (see Figure 9.1). A key aim was to investigate and demonstrate the potential of white space spectrum for providing broadband access to remote, difficult-to-reach rural areas in challenging terrain. The 18-month project involved the planning and installation of white space radio links from the local telephone exchange to eight premises in the surrounding area, as well as backhaul connectivity from the telephone exchange to the mainland and then on to BT's IP backbone for access to the Internet.

As well as assessing the technical ability of the network to provide broadband access, a further aim was to investigate the extent to which the white space broadband transmissions would be able to co-exist with Digital Terrestrial Television (DTT) transmissions without adversely affecting TV reception, and to what extent theoretical predictions would match measurements made in the field. This, it is hoped, would help to inform a number of decisions being considered by Ofcom with regard to regulation of white space access in the UK.

9.1.1 *The Project Partners*

Six partners formed the consortium that was set up to carry out the project:

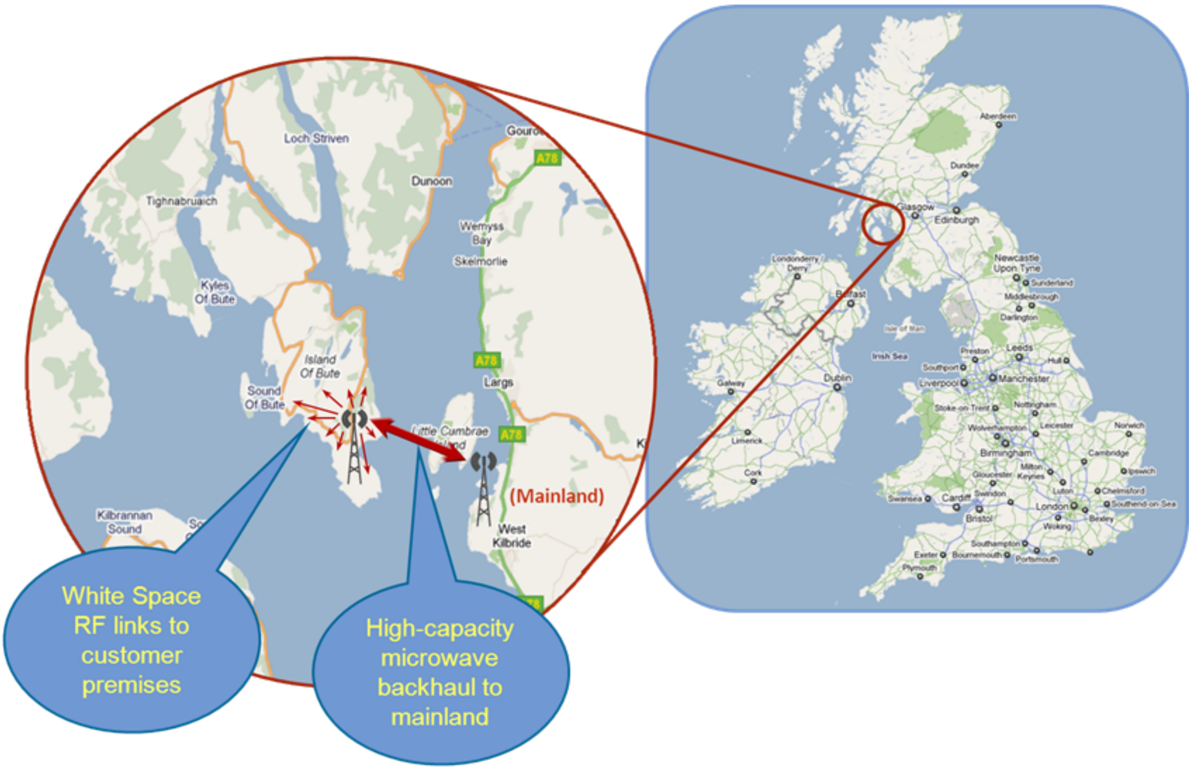

Figure 9.1: High-level illustration of trial white space network on Bute.

- **Steepest Ascent, Ltd** - a privately owned SME with its head office in Glasgow, UK and an office in Los Angeles, USA. Steepest Ascent was the lead partner in the consortium, responsible for managing the project and providing engineering expertise in RF planning and installation.

- **BT** - one of the world's leading communications services companies, operating in more than 170 countries worldwide. Representatives from BT Innovate and Design and from Openreach were part of the project consortium. Openreach led the installation of infrastructure equipment in the local telephone exchange and the provision of backhaul connectivity to the mainland and the backbone IP network. BT Innovate and Design provided engineering expertise and prototype WiMAX-based white space radio equipment for the project.

- **BBC Research and Development** - BBC R&D is at the core of the BBC's efforts to be at the cutting edge of media technology, and drives the exploration of exciting new production tools and distribution technologies. The BBC led the RF test and measurement activities on Bute, and provided technical expertise on DTT coverage predictions and interference modelling.

- **Berg Design, Ltd** - industrial design engineers who provide unique, tailor-made solutions from initial product design to full manufacturing support. Berg provided consultancy and mechanical design support for a first-generation extended-reach UHF/GHz base station mast.

- **Netpropagate Systems, Ltd**- UK operating subsidiary of Netpropagate Corporation, based in Los Angeles, USA. Netpropagate's core product is a next-generation video conferencing and collaboration solution for mass deployment using standard PCs and standard broadband. This formed one of the user applications used in the project.

- **University of Strathclyde**- the University of Strathclyde's Department of Electronic and Electrical Engineering is one the largest in the UK. Staff from the Department's Centre for White Space Communications provided prototype WiFi-based white space radio equipment for the test bed on Bute, and were heavily involved in the practicalities of installing and configuring the radio network.

9.1.2 *Implementing the Plan*

The project was implemented in four work packages:

1. **Installation and commissioning of the network.** TV-band white space transceivers were installed at eight trialists' premises and the aerials were pointed in the direction of the telephone exchange, where a white space base station mast was erected. The telephone exchange was equipped with a dedicated 18 GHz backhaul microwave link (not white space) to the mainland, where an IP connection to the BT backbone was made. After testing, the network was activated and the trialists were encouraged to use it normally.

2. **Modelling, laboratory testing, and field measurements.** Field measurements were made (during a 10-day period in June 2012) in order to characterize the performance of the network and evaluate the impact on DTT reception. Comparisons were made with predictions obtained from theoretical models and laboratory tests.

3. **Assessment of network operation and user experience.** The operation of the network was monitored while video-streaming took place, and trialists took part in video-conferencing sessions to test the network's ability to support broadband applications. A user survey was also carried out towards the end of the trial period, in order to gain insight into the trialists' experiences and their views on the connectivity provided to them during the trial and on broadband in general.

4. **Technical R&D and development of self-powered masts.** Technical R&D activities were carried out in relation to self-powered radio communications masts (using wind and solar energy).

9.2 INSTALLING AND CONFIGURING THE NETWORK

Figure 9.2 shows a high-level diagram of the network. A high-capacity 18 GHz microwave backhaul link was set up between the telephone exchange at Kilchattan Bay on Bute and West Kilbride on the mainland, where a connection to BT's IP backbone was made in order to provide Internet connectivity for the trialists. Point-to-Multipoint white space radio links operating in the TV band were set up between the Kilchattan Bay telephone exchange and trialists' premises. This involved the installation of white space Customer Premises Equipment (CPE) at trialists' premises and the construction of a white space base station mast in the grounds of the telephone exchange. The eight trialists' locations were split into two groups of four: Trialists in Group 1 were equipped with white space radios based on WiFi technology which was modified to operate within a single UHF TV channel; trialists in Group 2 were equipped with white space radios based on WiMAX, operating in a different TV channel from that which was used for Group 1.

9.2.1 *White Space Radio Equipment*

Two types of white space radio equipment were used in the trial:

- Prototype equipment from the University of Strathclyde's Centre for White Space Communications, based on XR7 WiFi technology from Ubiquiti Networks. A number of modifications were made, including scaling of the bandwidth down to 5 MHz so that transmissions would fit within a single, 8 MHz-wide TV channel. This equipment was used for trialists in Group 1.

- Equipment from Airspan Networks, based on WiMAX (IEEE 802.16e), configured to operate within a single, 8 MHz-wide TV channel, using 2x2 MIMO with antenna polarizations of ±45°. This equipment was used for trialists in Group 2.

In each group, uplink and downlink radio transmissions between the base station and trialists' CPEs took place using Time Division Duplexing (TDD). The non-operational test licence issued by Ofcom allowed for three 8 MHz channels to be used if required, but at any one time, only two were utilized in the network: one for the trialists in Group 1, and another for the trialists in Group 2.

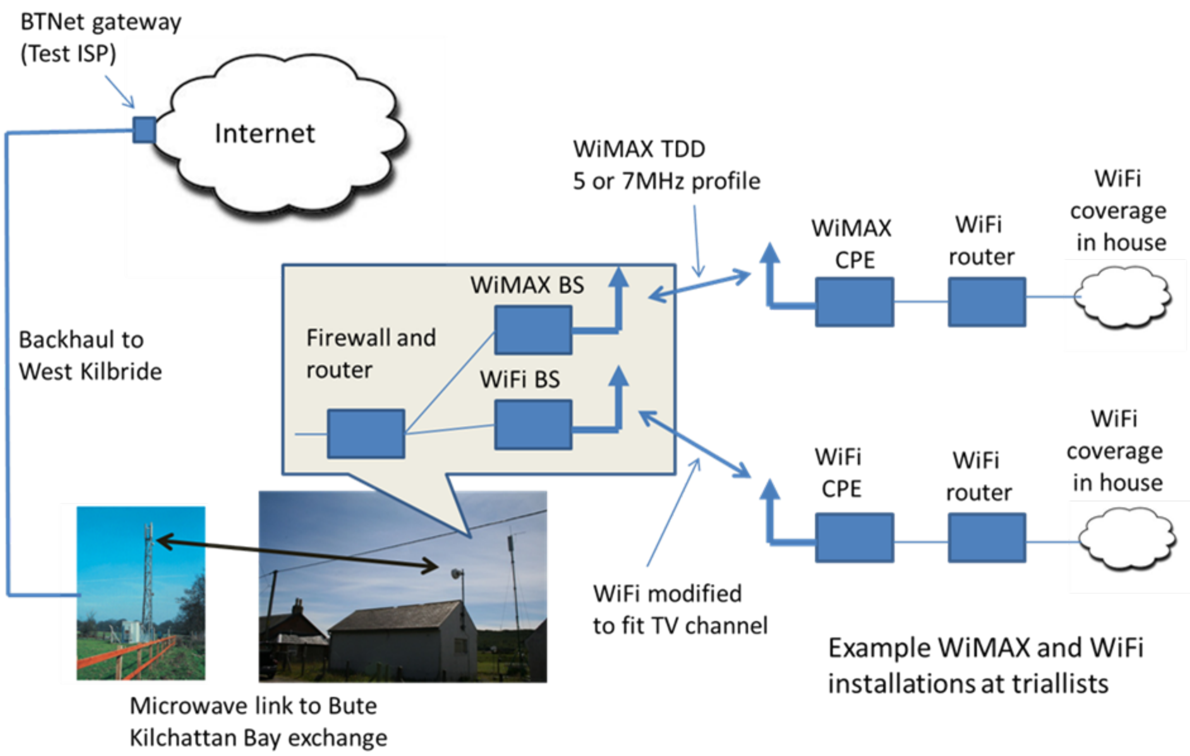

Figure 9.2: High-level illustration of trial white space network on Bute.

Customer Premises Equipment (CPE)

CPE units comprising a white space transceiver and aerial were installed at trialists' premises, as shown in Figure 9.2 and 9.3. The white space transceivers were mounted externally and connected to an Ethernet cable which was fed into the premises.

Inside the premises, a small Ethernet/WiFi router was supplied and configured to allow a number of devices within the home to be connected to it. (The provision of a pre-configured router allowed trialists to easily add end-user devices within the home without there being any need to modify the address space of the master firewall.)

The Ethernet cable was also used to deliver electrical power to the externally-mounted white space transceivers, using Power-Over-Ethernet (POE).

Base Stations

A mast was built at the local telephone exchange and fitted with a white space base station pointing roughly westwards for the trialists in Group 1 and one pointing roughly northwards for the trialists in Group 2. The set-up is shown in Figure 9.4.

Figure 9.3: CPE installations at trialists' premises.

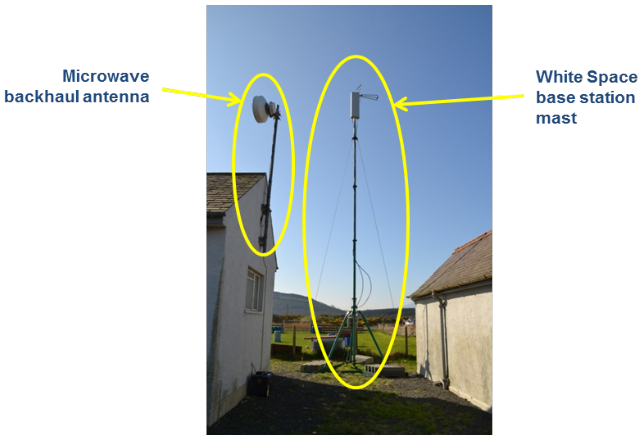

Figure 9.4: White space base station mast at local telephone exchange. (The 18 GHz backhaul dish antenna is also visible.)

Backhaul to the Mainland

Backhaul was provided using standard products from BT Global Services, BT Wholesale, and Openreach. Internet access was provided by a BT Net connection. An 18 GHz microwave link was installed between the island and the mainland - a distance of 12 km. (The microwave antenna at the exchange can be seen in Figure 9.4.)

9.3 DATA THROUGHPUT MEASUREMENTS

Data throughput on the network was measured and analysed in a number of ways, including:

- Laboratory measurements, aimed at characterizing the equipment 'on the bench' in controlled conditions;

Prototype TVWS Technology	Connection Protocol	Maximum Uplink Throughput	Maximum Downlink Throughput
WiMAX (5 MHz B/W) (36 dBm EIRP in total, i.e. 33 dBm per port)	TCP	3.5 Mbit/s	8.9 Mbit/s
	UDP	3.4 Mbit/s	16.4 Mbit/s
Wi-Fi (35 dBm EIRP)	TCP	7.6 Mbit/s	3.8 Mbit/s
	UDP	8.0 Mbit/s	5.2 Mbit/s

Figure 9.5: Summary of data throughput measurements taken at selected test points on Bute.

- Vehicle-based measurements made at various locations in and around the trial area;
- Measurements made at trialists' premises using the previously-installed white space CPEs.

Figure 9.5 shows the maximum data rates that were achieved from the mobile measurements. With the WiMAX system operating in its 5 MHz bandwidth mode, and the base station transmitting at 36 dBm total EIRP (i.e. 33 dBm per MIMO port), UDP data throughput rates of about 6-16 Mbit/s (downlink) and 1-3 Mbit/s (uplink) were observed, depending on the location. TCP throughput rates were lower than expected, given the good UDP throughput. A problem by which the traffic source and destination fail to co-ordinate and adjust the TCP window size in certain test configurations was subsequently discovered, and it is thought that this might be responsible for the lower-than-expected TCP throughput values.

The WiFi system was configured to use a 5 MHz channel width and a maximum base station transmit power of 35 dBm EIRP. Data throughputs of 1-5 Mbit/s (downlink) and 2-8 Mbit/s (uplink) were observed. As was also observed in the laboratory experiments, the WiFi equipment, as configured, favours the uplink; this is a limitation of the firmware used to drive the prototype radio equipment used in the trial.

It is worth noting that at distances of about 5 km, the mobile antenna was lowered to approximately 2.5 metres rather than fully extended to 10 metres. This seems counter-intuitive as far as normal radio planning practice is concerned, but a white space antenna positioned at a height of 10 m will pick up more DTT signal power than one at 2.5 m. Reducing the height of the antenna helps to reduce interference from DTT transmissions, although this needs to be balanced with the need to maintain adequate antenna height in order that a sufficient level of white space signal power is received in the first place.

Figure 9.6 shows the rates achieved from measurements at selected trialists' premises. The measurements were scheduled to run during the night in order to minimize the likelihood of conflicting with trialists' routine use of the broadband links, and they involved the transfer of data from a PC at the telephone exchange to laptops connected to the modems in the trialists' premises. Measurements were run for several minutes, with multiple connections simultaneously active in order to investigate how well the radio systems can share the bearers among users.

The throughput of the WiMAX system was greater than that of the WiFi system, but it should be borne in mind that:

- The WiMAX radios were configured to operate in a 7 MHz bandwidth mode and to make use of MIMO techniques;
- The WiMAX trialists' premises were closer to the exchange than those of the WiFi trialists, and therefore the WiMAX CPEs were each operating with good carrier-to-noise ratios, facilitating operation in the 64-QAM modes;
- The WiFi kit used for this project was modified for use on Bute without any optimization.

It is worth noting that beyond about 2 km from the telephone exchange, the performance of the WiMAX equipment was found to decrease to the point where it fell below that of the WiFi equipment. This is contrary to predictions derived from the laboratory measurements, and possible explanations include: unwanted downtilt on the WiMAX BS antenna; poor performance of the CPE; interference on the uplink; poor ACS on the uplink receiver; other installation issues. Further work is required to understand why the WiMAX equipment behaves in this way at present.

9.4 COVERAGE AND INTERFERENCE ANALYSIS

White space devices will be permitted to use white space spectrum on a licence-exempt basis only if they do not cause harmful interference to licensed transmissions such as DTT broadcasts or properly-licensed PMSE transmissions. Therefore, a key aim of the trial on Bute was to assess the impact of the white space transmissions on DTT reception in the vicinity of the trial. To this end, several activities were carried out:

Several DTT receivers were tested in the laboratory to assess their sensitivity to co-channel and adjacent-channel interference. DTT and white space coverage predictions for the trial area on Bute were made, using the UK Planning Model (UKPM), and corresponding predictions of co-channel interference to DTT by white space transmissions were made. Field measurements of actual DTT and white space signal strengths in the trial area were made, along with a corresponding assessment of co-channel interference to DTT transmissions. In addition, measurements

Prototype TVWS Technology	Connection Protocol	Number of Simultaneous Links	Total (Aggregate) Downlink Throughput on Bearer
WiMAX (7 MHz B/W) (36 dBm EIRP in total, i.e. 33 dBm per port)	TCP	1	14 Mbit/s
		2	22 Mbit/s
		3	23 Mbit/s
	UDP	1	23 Mbit/s
		2	24 Mbit/s
		3	25 Mbit/s
Wi-Fi (35 dBm EIRP)	TCP	1	2 – 4 Mbit/s
		2	3.5 – 4.5 Mbit/s
		3	3.8 Mbit/s
	UDP	1	3.3 – 4.5 Mbit/s
		2	4.0 – 4.5 Mbit/s
		3	4.4 Mbit/s

Figure 9.6: Summary of total (aggregate) downlink throughput on radio bearer, measured while downloading data to selected trialists' premises simultaneously.

of DTT signal strength were made at various test points distributed across Bute, and these were compared with predictions obtained from the UKPM. The aim of this activity was to confirm the validity of the UKPM itself, as the UKPM is likely to form the basis for constructing the UK's geo-location database for white space.

9.4.1 *Laboratory Testing of DTT Protection Ratios*

Laboratory tests were carried out on fourteen DTT receivers, using various candidate white space technologies as interferers. The DTT receivers were a varied mix of devices which included set-top boxes (STBs), integrated digital televisions (IDTVs), and personal video recorders (PVRs). Seven of them used can-type tuners; the other seven used silicon tuners. A wide variation in performance was observed among the fourteen receivers. The performance of certain receivers was also found to depend on the nature of the white space interference; certain white space transmissions tend to cause more severe problems than others, although this depends upon the architecture of the DTT receiver's RF tuner. Figure 9.7

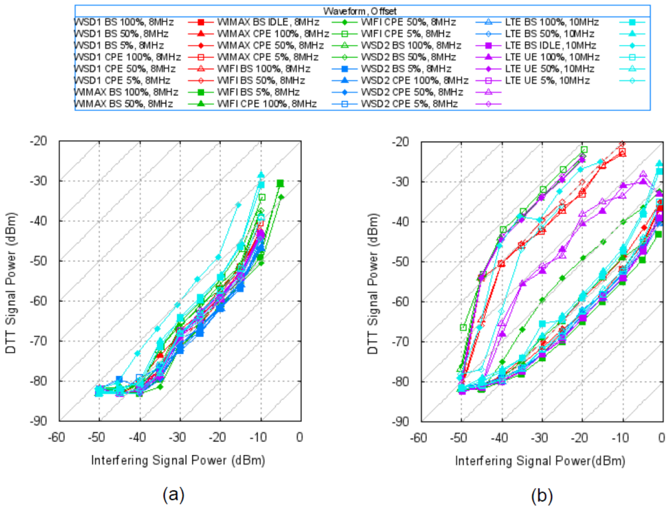

Figure 9.7: DTT receiver performance in the presence of various types of white space interference. (a) A 'typical' receiver; (b) A 'poor' receiver.

shows the performance of two DTT receivers in the presence of various types of adjacent-channel white space interference (the graphs show the points at which the picture just starts to break up). The performance of the receiver in Figure 9.7(a) is relatively consistent for various types of white space interference. The receiver in Figure 9.7(b), however, shows wide variation in performance in the presence of different types of white space interference. Of the fourteen receivers tested, three exhibited problems due to non-linearity caused by the presence of pulsed white space transmissions.

9.4.2 *Quality of White Space Channels*

When considering the issue of co-existence between WSDs and DTT, much of the attention to date has focused on the extent to which the transmissions of WSDs might affect DTT reception. However, potential users of white space spectrum are likely to be interested in the extent to which DTT signals from TV transmitters might impinge upon white space channels that are available for use in a particular location. (When a WSD is given permission to use a white space channel in a particular location, there is no guarantee that the channel will be free of DTT signals that could potentially interfere with the white space transmissions.)

From the numerous DTT signal strength measurements that were taken across Bute, estimates of white space channel availability were made for each test location, and the residual DTT signal strength in each of those channels was calculated. This gives a rough indication of the quality of each white space channel at each test location. Figure 9.8 shows the resulting Cumulative Distribution Function (CDF), from which it can be seen that at least 75% of locations have a residual DTT

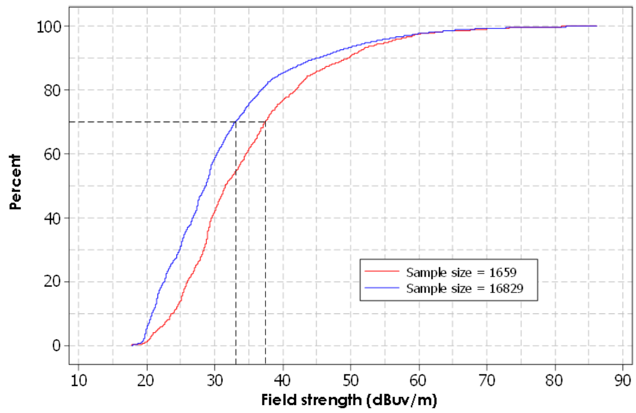

Figure 9.8: Cumulative Distribution Function (CDF) for residual DTT signal strength in white space channels on Bute.

field strength of less than 40 dBμV/m. This implies, therefore, that some 75% of white space channels on Bute would be usable in practice.

9.4.3 WSD-to-DTT Coupling Measurements

Any coupling from a white space device to a TV aerial creates an opportunity for interference to be injected into the DTT receiver. The effects of WSD-to-DTT coupling depend on the relative positions and orientations of the antennas. In order to assess WSD-to-DTT coupling in the field, measurements were made at various premises - mainly those of trialists but also those of a few non-trialists. The measurements involved the taking of power readings from the output of the TV aerial download, which represents the signal that would normally be entering the DTT receiver.

Figure 9.9 and 9.10 shows two CPE installations on Bute. In Figure 9.9, the TV aerial and white space CPE antenna are 14 metres apart and their boresights are offset from one another by 80°. This is considered to be an example of a 'good' installation: the antennas are sufficiently far apart and their boresights sufficiently misaligned to result in a high WSD-to-DTT coupling loss. (The coupling loss was 82 dB.) In Figure 9.10, the TV aerial and white space CPE antenna are mounted on the same pole, with a separation of approximately 1 metre in the vertical direction. Their boresights are offset from one another by 30°. The WSD-to-DTT coupling loss was only 22 dB, and although all of the property's TV sets were functioning without any apparent problems, this is nevertheless considered to be a 'poor' installation.

In order to minimize WSD-to-DTT coupling, factors such as physical separation and boresight offset of the DTT and TVWS aerials at the customer premises are clearly important. In addition, several of the trialists' installations included amplifiers of unknown gain and TV aerials of unknown quality, thus adding to the complexity of installation.

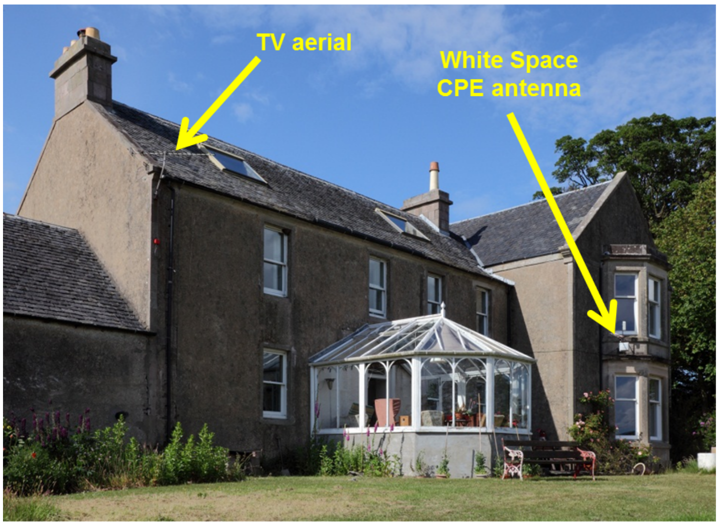

Figure 9.9: As far as WSD-to-DTT coupling is concerned, this is considered to be a 'good' installation.

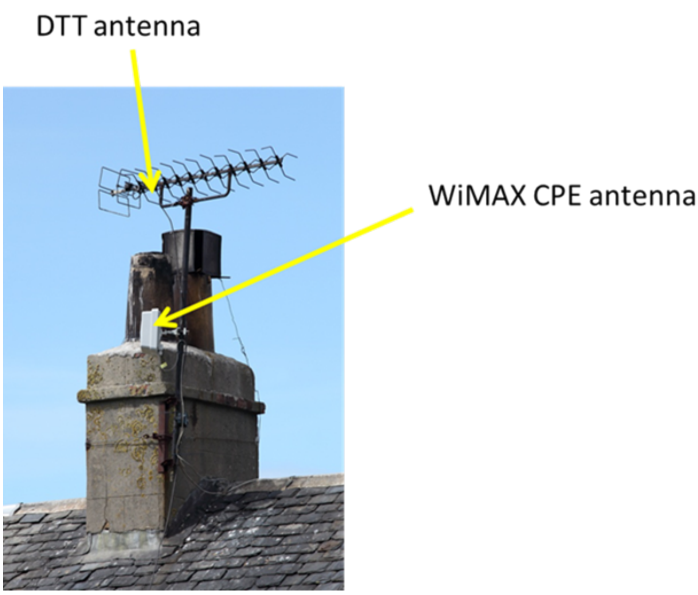

Figure 9.10: As far as WSD-to-DTT coupling is concerned, this is considered to be a 'poor' installation.

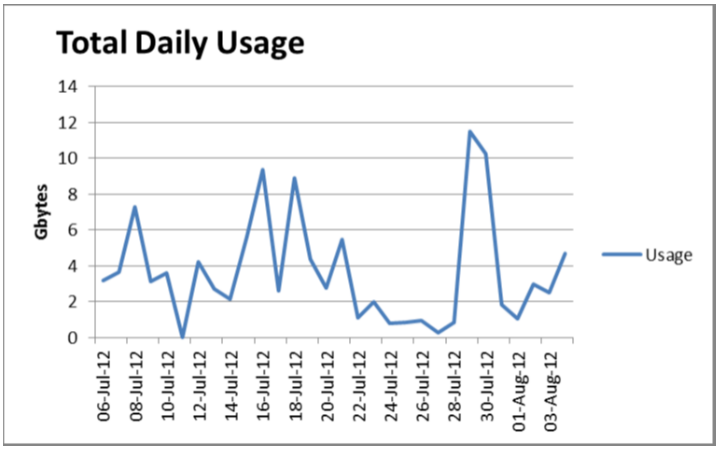

Figure 9.11: Daily usage statistics for the whole network over a one-month period.

9.5 NETWORK OPERATION AND USER EXPERIENCE

Many of the residents in the trial area are farmers, and there is increasing pressure on them nowadays to carry out various administrative tasks on line rather than by paper or telephone. The same is true of hotel owners, and fast, reliable access to the internet is becoming an essential tool for many businesses.

The white space trial on Bute involves a real network with trialists making real use of the broadband services provided to them via white space spectrum. Figure 9.11, for example, shows the total daily usage measured over a one-month period during the summer of 2012. The trialists have spoken very positively about the broadband connectivity that they have been receiving as part of the trial, and the value that it has brought to their personal and business lives. When asked if expectations had been met as a result of the white space trial, one trialist responded: *"Very much so —compared with what we had before, this is excellent."*

9.6 FURTHER EXTENDING BROADBAND REACH

A proposed method of further extending the reach of broadband provision involves the use of self-powered 'relay' masts located at suitable locations such as a hilltop, and connected wirelessly to the local telephone exchange or some other kind of aggregation point. Self-powered masts have the advantage of not requiring an electricity supply, making them ideally suited to locations where such an electricity supply does not exist.

This concept has been considered as part of the project, and prototypes have been developed and manufactured (see Figure 9.12). Initial

Figure 9.12: Prototype 'Wind-Fi' mast.

tests suggest that the concept is viable, and further test and development activities are being planned.

9.7 SUMMARY AND CONCLUSION

The white space rural broadband trial on the Isle of Bute has been extremely useful for gaining insight into the viability of using white space spectrum for rural broadband provision, and has successfully demonstrated the potential of white space technology through the use of real-world applications such as video streaming and video conferencing. The trialists have embraced the network for a wide range of uses related to working life, social life, leisure and recreation, online shopping, education, etc. They speak very positively about the broadband connectivity they have been receiving as part of the trial, and the value that it has brought to their personal and business lives. The provision of adequate broadband connectivity in rural areas is clearly very important in today's society, and the benefits of using white space spectrum are applicable not only to remote parts of Scotland but also to remote areas in many other parts of the world.

9.8 ACKNOWLEDGEMENTS

The author expresses thanks and acknowledgements to the Technology Strategy Board for its support throughout the project, and to colleagues in each of the partner organizations for their contributions to the main project report, from which this case study is derived. Particular thanks are due to Mark Waddell (BBC), Shyamalie Thilakawardana (BBC), Tim Harrold (BBC), Michael Fitch (BT Innovate Design), Andrew Garrett (BT Innovate Design), Chris Gibbs (Openreach), Malcolm Starke (Openreach), Malcom Brew (Steepest Ascent), and Faisal Darbari (Centre for White Space Communications, University of Strathclyde).

9.9 FURTHER INFORMATION

Further information regarding the Isle of Bute White Space Trial can be found at: http://www.wirelesswhitespace.org/projects/white-space-trial-on-the-isle-of-bute.aspx