5G Rural Integrated Testbed

D6.11 Interim Final Report

Network Technical Design and Deployment

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1. Introduction

This report brings together the outputs from the two network partners on the 5GRIT project as part of the Department for Digital, Culture, Media and Sport 5G Testbeds & Trials Programme, Quickline Communications Ltd (QL) and Broadway Partners Ltd (BP). The two companies set out with similar objectives, using similar technologies; but the equipment they chose to use and the regions of the UK in which they built their networks meant that their results and conclusions were significantly different.

Therefore, this report comprises the individual reports from the individual reports from the two partners, with an executive summary that brings together the key conclusions from both trials.

One further point is that both networks were significantly delayed in their build programme and as a result evaluation has not yet been completed. Therefore, the trials are continuing into Phase 2 (extension until end September), but whereas QL is continuing to evaluate their networks and use these networks to support the activities of the other operational work packages. BP are continuing their trials only for a further 2-3 months to gather sufficient data to enable them to prepare their final report.

2. Summary of Conclusions

2.1. TVWS

- QL had mixed deployment results.
    - While the base station implementation between Mount Hooley [Alston, Cumbria] and the customer premises at Nenthead Mines and the Youth Hostel [to assist and support the tourism and farming applications] have worked and brought some successes to the project.
    - The installations in both Lovesome Hill, and Longhills, Lincolnshire, did not work no matter how hard the technical teams tried various solutions suggested by the equipment manufacturers
- Factors affecting these results
    - Ground clutter and available TVWS contiguous channel spectrum for each selected area.
        - In relation to the Longhills area the available spectrum channels suggest that QL should have been able to bond three or more channels together and so attain superfast speeds to support the teleworker and rural broadband user cases. The reality of this does not always reflect from the desk-based analysis pre-work, in so far as soon as the third channel is bound, the service drops back to single digit Mbps connection, regardless of the combination of three channels used from the available spectrum where shown.
        - In Alston the was less clutter and a 'cleaner' spectrum so solid connection rates of ~50 mbs were achieved with stability.

- BP undertook their trials in rural areas in Scotland and posed two questions:
    - Question 1 - Are current propagation models utilised in dynamic spectrum regulatory framework transferable to WSD planning and deployment?

    - Question 2 - Has TV White Space come of age? Can White Space technology be utilised now to deliver applications such as broadband and achieve modern performance standards?
- Their answers were:
    - Question 1 - No, it would appear that Hata Extended with the suburban / urban clutter assumption does not transfer to good results when planning TVWS links. The best propagation model we found was Longley Rice with a Terrain 50 dataset.

    - Question 2 - USO universally achievable in testing. TVWS is a good technology in a lot of areas for NGA speeds with 70Mbps achieved during testing.

Considering the trials of both partners it appears that where there was little clutter and a relatively free spectrum, it was possible to use TVWS, but its application in any other areas is not suitable with the current equipment.

It is understood that new releases of equipment are scheduled for late 2019 and it is planned that further trials by one or both of the partners will be undertaken to assess the market readiness of TVWS in the UK.

2.2. 60 GHz

- QL's experience with point to multi-point 60 GHz equipment is more positive than TVWS.
    - They successfully tested individual point to point links and single access points running a smaller number of connections
    - They have to test multiple transmitters in a small geographical highly dense area all running simultaneously.
    - QL's trial users have consistently reported high double / triple digit speeds tests as revealed through the implementation and milestone reporting.
- BP's starting point was that the 60GHz spectrum is utilised for short distance, high speed communication and that potential applications may develop once Ofcom has completed the process of clearing higher frequency to enable more high-speed access specifically for 5G fixed wireless access.

Owing to its propagation characteristics, most notably its oxygen absorption rate and susceptibility to clutter, it is questionable if the technology can usefully be utilised in a rural environment to deliver low latency, high speed performance – and Broadway has set out to answer that question.

- As with TVWS, two key questions were posed:

    - Question 1 - Should 60GHz technology be considered at all for rural deployments?
    - Question 2 - Does new point to multipoint / mesh technology offer any benefits in a rural environment?
- Answers
    - Question 1 - 60 GHz has a pivotal and complementary role in rural environments.
    - Question 2 - Yes, there are NLOS and deployment benefits to 60GHz mesh.

Both partners found considerable success using 60 GHz equipment in rural areas, recognising its limited range. Customers were experiencing stable broadband connections >50 mbs.

In Phase 2, QL plans to test the limits of density by additional networks in the Ingoldmells area – which as can be seen, is primarily a holiday area with large numbers of transient customers.

3. Executive Summary - Quickline

The purpose, identification and creation of a phase 1 network would be to facilitate the installation of selected technologies to be tested as part of this trial, understand the intricacies of installation given the relative infancy of the technologies, the operational parameters and conditions of optimum runtime, and create a blueprint for future roll outs, making certain to log any lessons learned throughout the process.

Depending on the success levels of each technology to deliver superfast broadband services in support of the use cases [rural, tourism and farming], this would determine the point at which it could be considered for upscaling into a phase 2 trial, and clearly a much larger project to harvest significantly increased performance data. Conversely if the technology readiness level [TRL] was gauged to be insufficient, this would be deemed sufficient grounds to not carry forward into phase 2 upscale testing.

Within a phase 2 trial, the technology selected would be proposed for more in depth testing in a dense environment, and if proven operationally and technically viable, would suggest the technology to be used to deliver commercial competitive advantage in an area which had previously been considered unserviceable.

The model for such would be to identify a limited concentration of potential end users [EU], and enlist into the trial, ensuring they were comfortable to accept the terms of engagement given additional consortium members may wish to make contact to satisfy their work packages [WP]. The ongoing support of the phase 1 test bed would operate throughout the duration of the trial, with the EU's providing feedback, speed tests and narrative throughout. This feedback is key to establishing inclusion in the phase 2 trial.

The team behind such a deployment would consist of customer services to coordinate the engagement, equipment procurement and project management; the network team, for planning and execution of the design and equipment set-up, and finally the field based engineers to link the networks team to the EU point of installation.

The continuous improvement cycle would be in place throughout phase 1 trial to monitor the connections, discuss issues with EUs to translate into remedial activities which can then be monitored and reported.

4. Introduction - QuickLine

In order to generate a phase 1 test bed network for the technologies selected, it was necessary to understand a geographical area for each, capabilities and limitations, which could provide a thorough test for the use cases composed as part of this trial. The challenge being the identification of such an area to sufficiently fulfil the test criteria, [superfast broadband provision] it was necessary for Quickline [QL] to draw on knowledge of historically failed and borderline / fringe installations, and the rationale behind such failures, which led to the identification of a potential installation base.

In terms of the TV White Space [TVWS] technology the contributing factors for its deployment were:

- Non Line of Sight [NLOS]
- Spectrum channel bonding to facilitate superfast connection

In regard to the 60 GHz technology deployment, those factors for its selection and deployment were:

- Small scale concentration of connections
- Line of Sight [LoS]
- High speed / low latency connections

4.1. TVWS

The installation opportunities for TVWS were gained from reviewing remote broadband areas where installations using traditional fixed wireless equipment [FWA] had failed given a particular challenge, such as link length, or surrounding environment etc., as can be demonstrated below examples relating to Longhills and Altson respectively in **Figure 1** & **Figure 2**:

Note the remote geographical location of Longhills below.

(image removed)

Figure 1

(image removed)

Figure 2

The use case users in the Longhills implementation area were able to obtain 1-2 Mbps ADSL services with virtually no choice in the area to choose from alternative providers, and so unable to gain access to superfast services using any incumbent provider.

The use case for the implementation at Alston differed in that the distance and terrain were more of a challenge given the near line of sight [NLoS] but the use cases were not solely rural broadband users, but a wider scope to incorporate farming and tourism use cases. In so doing it provided links with WP3 and WP5.

4.2. 60 GHz

Similarly, to test the 60 GHz equipment, QL understood the issues faced by a local community in Auckley having already canvassed the area to determine any potential service uptake. In terms of background this was a housing estate which had not benefited from any distributed fibre installation when under construction, but reliant instead of ADSL services operating at sub 10 Mbps; see **Figure 3**

(image removed)

Figure 3

The use cases for this area centred around rural users, families with children who were either teleworkers or required internet based services for homework completion.

5. Research Question & Implementation

5.1. Can 5G deliver 30 Mbps Broadband Compliant with BDUK's State Aid Requirements in Rural Areas at Scale?

Selection criteria for any technology trial has its challenges. Fixed wireless access [FWA] equipment has a long and documented history where ground clutter or terrain obstacles impedes connectivity and performance. Any such element which bisects the line of sight [LOS] between the base station and the customer premises can disrupt the signal and impair the connection quality. In terms of how this translates through to the end user experience, it can be seen as an increase in latency and a degradation of signal quality; in turn this leads to the generation of support tickets but at its worst, field-based service calls and a poorer end user experience.

In terms of the differing technologies considered throughout this trial, the objectives of their inclusion were consistent. In the geographical areas selected we have a number of potential use cases, all of which are unable to obtain a superfast 30 Mbps plus connection. Which of these technologies could facilitate such a connection given the physical and geographical restraints where FWA implementations had previously failed?

5.2. TVWS Trials

5.2.1. TVWS - Bardney to Longhills

QL was aware of a rural community with whom it had previously attempted to deploy FWA technologies, however given the geographical locale and surrounding tree restrictions, it proved impossible to improve upon to provide a superfast service. Given the proximity of around 6 miles to QL's transmitter mast located at Bardney, North Lincolnshire, and a desktop survey completed to identify line of site [LoS] and distance, QL determined that this site could be a prime candidate to implement TVWS technologies. The below **Figure 4** depicts Longhills TVWS customer connections towards the left of the image, while Bardney TVWS transmitter located towards the right.

(image removed)

Figure 4

Given the issues encountered with channel bonding in this particular area, the feedback from end user use cases was not always positive and certainly fell short of the delivery of 30 Mbps. The range of speed tests delivered between 5-20 Mbps in reality. Indeed QL's field based service engineers have made several trips to the area to undertake realignment with a view to improving connectivity and throughput. Any economic benefit in this use case can be perceived as improving the teleworker's ability to complete activities without the requirement to travel to the office, undertaking tasks remotely and enhanced remote access meeting capabilities; furthermore, it has the potential to reduce carbon footprint with lower demands on travel.

5.2.2. TVWS - Mount Hooley to Nenthead Mines, Alston

Through interaction with Cybermoor [CYB], QL was made aware of a potential use cases near Alston, Cumbria, relating both to tourism and farming. The use case for farming has further links to WP3 to allow for enhanced metrics to measure crop farming efficiencies, while the latter allowed for the installation of TVWS technology into Nenthead Mines to service the local tourism aspect; in conjunction with World Around Me [WAM] who has developed the tourism app [for IOS and Android] to allow for better tourism promotion of the area; **Figure 5**. The perceived economic benefits for the technology deployment into this area is largely drawn from increased tourism; the saleability of using the WAM mobile application to provide further enhanced augmented reality content to visiting tourism, will have a positive effect on how the attraction is marketed. The realised speeds delivered in this area ranged between 20-25 Mbps.

Figure 5

5.2.3. TVWS - Mount Hooley to Youth Hostel, Alston

CYB was also able to advise QL, given its valuable knowledge of the area, a further potential implementation of TVWS would be to facilitate a link to the Youth Hostel - **Figure 6**; in so doing it could provide potentially superfast speeds to a client endpoint, and further enhance the economic benefits use case for tourism. Added to this the WAM application could be used to provide augmented reality aspects for the surrounding areas and harbour the potential to retain visitors to the area to longer. The realised speeds delivered in this area ranged between 20-25 Mbps given 2 channel bonding.

Figure 6

5.2.4. TVWS - North Yorkshire - Lovesome Hill

The objective and reason for inclusion was to use a TVWS implementation to end users to address non line of sight [NLOS] and ground clutter challenges reported by <u>**existing**</u> customers. Deployed into this area are several fringe connections using 5GHz; the existing network has a number of poor line-of-sight band B and band C end users. These connections have deteriorated as trees came into leaf which makes them ideal candidates for TVWS technology deployment to further enhance testing.

These end users were connected directly to a central base station in the same location as the existing band B and C equipment.

(image removed)

Figure 7

The Lovesome Hills environment will provide a direct comparison between line of sight and non line of sight technologies. A number of test customers have been installed and have been operating over line of sight technology. These test customers have had their service and signal levels monitored.

The following photos represent the site that will host the base station. The work completed so far includes:

- Provision of new cabinet structure to house relevant electronics
- Cable run
- New bracketry
- Relevant electronics to deliver connectivity into new base station

Figures 8, 9, 10

The difficulty with the implementation at Lovesomehill was it is surrounded by several points of interference and as such, despite assurances from the hardware vendor and OFCOM database, it became impossible to implement a link to those customers who already had traditional FWA installations; the site has since been decommissioned.

5.3. 60 GHz

5.3.1. 60 GHz - Auckley, Doncaster

The use cases for deployment of 60 GHz technologies in Auckley, Doncaster, were geared supporting supporting the teleworker / home user use cases. In this area QL has identified through canvassing local residents, the lack of apparent superfast internet connectivity in the area; given the proximity of local housing to QL's transmitter mast, it made sense to deploy 60 GHz technologies in this area and as part of the trial, seek regular feedback from the end user use cases to determine whether their perceived impression of service delivery had improved.

In a high percentage of cases the feedback post installation was received favourably among the test bed use case; much of the feedback centred around high double digit [and in some cases triple digit] download speeds perceived as a real economic benefit, as well as a perceived increase in the number of potentially connected devices without any notable service degradation to superfast speeds, [such as buffering] see **Figure 11,** depicting misalignment. In this particular use case the EU's had reported speeds well in excess of 30 Mbps which assisted in identifying this technology as being eligible for consideration for a phase 2 deployment in a more densely concentrated deployment.

Figure 11

Figure 12

The Figure 11 shows how, after a windstorm, the end user's client installation has become mis-aligned and as such, the user reported speed degradation.

Figure 12 shows the positive effect post field based engineer realignment and so, restoration of services.

Feedback from the use case candidates was purposefully received given the potential for future inclusion into a phase 2 trial wherein its deployment into a concentrated, more densely populated area, would be seen to be the ideal opportunity to undertake further trials and determine its capabilities.

5.4. Additional Aspects of Network Deployment

In the sense of collaboration throughout the project. QL has engaged with consortium partners where required to facilitate technology solutions. Two of note related to BBSR and Precision Decisions [PD].

5.4.1. BBSR

In order to fly drones beyond visual line of sight [BVLoS] and link back into the 5G network, BBSR engaged with QL to request a recommendation for equipment selection and implementation. QL recommend a deployment of Cambium Medusa multi user, multi input / multi [MU-MIMO] output technology with beamforming to ensure qualification as a 5G technology. This has been successfully deployed at BBSR offices in Bedford to allow for its phase 1 controlled corridor BVLoS testing. Once controlled flight parameters have been established this has the ability to be transported to Precision Decisions and farms based in Alston to further facilitate the real time flight, data recording and transmission of crop analysis / livestock counting and management remotely, see **Figure 13**.

Figure 13

5.4.2. Precision Decisions

Given the distribution of QL's transmission infrastructure across North Yorkshire, this had the potential to lend itself to facilitate a link into Precision Decision using Cambium Medusa MU-MIMO and demonstrate further partner collaboration. In so doing it would facilitate BBSR to integrate its drone flying capabilities across PD's farming estates and capture real time flight recording of crop production / health / quality, and identify precise areas where remedial attention is required, **Figure 14**.

(image removed)

Figure 14

6. Key Learning Points

The following areas were some of QL's key learnings:

Technology Readiness Levels [TRLs]

- The choice of TVWS supplier had a significant impact on the project's deliverables from a QL perspective, and it could also be suggested this further extended to other consortium members who had responsibility to implement in their chosen geographical areas. Given the TVWS TRL, by comparison to commercially established equipment, QL has found diagnostics and equipment set-up challenging at best.
- Once next generation equipment becomes available QL may consider its deployment to replace existing equipment.

Working with overseas suppliers & equipment availability

- In regard to the TVWS equipment supplier, and the relative immaturity of TRL, QL encountered a significant delay in supply of equipment. This meant that between order placement and gaining active experience in its deployment in the field, there were periods of inactivity throughout each implementation milestone which were mitigated by QL focussing attention in favour of 60 GHz equipment, and look for alternative technologies to implement throughout test beds.

Alignment

- With any line of sight [LoS] and non line of sight [NLoS] technologies, alignment between base station and customer end point is key to ensure service provision and optimise the performance. Weather plays a major role in maintaining alignment and given the prevailing times of year QL has learned that wind and rain are significant contributors to adverse performance.

Use cases and end user adoption

- Ensuring systems are tested thoroughly in the lab before end users test them post deployment.
- Stigma of equipment installation; given the large footprint of TVWS equipment it was on occasion, not looked upon favourably to begin with and attracted negative criticism from the installation test bed. Equally there exists at present, a significant amount of negative press surrounding 5G technologies; the 5GRIT consortium has always sought and been provided with assurances from DCMS to refer any issues to Public Health England. Reassurances from Public Health England and attending the town hall meeting managed to mitigate some of the public concerns.

Management of end user expectations

- Throughout each deployment test bed, for both TVWS and 60 GHz equipment, QL has actively managed the expectations of end users. An example of which is that the TRL of the equipment was made known, and as such it will be prone to service issues and possible service drops from time to time, particularly in regard to inclement weather as was noted with the 60 GHz equipment.

Managerial

- Contracts - Public land owners and organisations not willing or able to respond accurately or timely, which led to the slow down of project momentum in particular the WP5. An example of which is when trying to implement infil mast sites, QL has completed site surveys and issued license documentation for potential mast holders to accept, without which we are unable to proceed. QL has experienced significant delays in moving such elements forward.
- Lack of adoption for using 5G applications - the concern being potentially not enough end users to undertake service testing and so produce a set of results which may not be representative of the input efforts; this challenge sits across all use cases.

Environmental

- Adverse weather [high wind, rain], has been a major contributory factor in delays to deployments and site surveys, which has led to rebooking of appointments and equipment necessary to complete the remedial actions.

Safety

- Safety concerns expressed over ‘new technology’ from public; usually this can be mitigated by attending community / parish council meetings where necessary to field questions from the floor, and a concerned public. Between Cybermoor [CYB] and QL we have attended several public meetings with a view to responding to questions submitted from the public to appease any anxieties raised from unofficial sources.

7. Results, Future Work, Conclusions

The findings and therefore conclusions revealed from phase 1 differ between technology deployments and use cases.

In respect of TVWS technology deployment, it is the view of QL that given the current TRL, it has had mixed deployment results. While the base station implementation between Mount Hooley [Alston, Cumbria] and the customer premises at Nenthead Mines and the Youth Hostel [to assist and support the tourism and farming applications] have brought some successes to the project, the same cannot be said to be true in both Lovesome Hill, and Longhills, Lincolnshire, deployed to support the rural broadband implementation.

A number of factors have led to these differences, chief among which are the combinations of ground clutter, and available TVWS contiguous channel spectrum for each selected area. For example, in relation to the Longhills area the available spectrum channels suggest that QL should have been able to bond three or more channels together and so attain superfast speeds to support the teleworker and rural broadband user cases. The reality of this does not always reflect from the desk based analysis pre-work, in so far as soon as the third channel is bound, the service drops back to single digit Mbps connection, regardless of the combination of three channels used from the available spectrum where shown.

Scaling this technology up into a phase 2 proposal clearly has significant challenges, particularly the combination of TRL, ground clutter and channel spectrum availability and choice of deployment location. One suggestion is to look to alternative TVWS technology providers and determine a comparison of capabilities which may provide more favourable results.

The conclusion at this stage for TVWS is that in order to progress this technology, QL requires a higher TRL in order to revisit the phase 1 trials, before any consideration can be given to progressing to phase 2 higher density deployment. Having consulted suppliers, QL believes that the higher TRL may become evident towards Autumn 2019; on its release QL may re-engage with the hardware vendors and also consider alternatives to test this view.

In respect of 60 GHz equipment, QL has experienced more consistent and positive results regarding the TRL; whilst we have tested individual point to point links and single access points running a smaller number of connections, we have not as yet been able to test multiple transmitters in a small geographical highly dense area all running simultaneously.

QL’s trial users have consistently reported high double / triple digit speeds tests as revealed through the implementation and milestone reporting.

In terms of ramping up to phase 2 we see 60GHz density as a key item to test. In so doing, the aim would be to obtain further insight into propagation, into link performance and into whether there are interference issues when the grid becomes more dense.

In terms of measuring interference, we will monitor the signal to noise ratio of the clients to AP connections. Furthermore QL plans to monitor the sustained modulation levels of clients as more connections are activated, by running iPerf tests from the core network to end users to monitor true link performance [across the link] as the density of the network increases.

The proposal and conclusion at this stage for 60 GHz equipment is to progress this technology into phase 2 testbed development, wherein it will coexist with established and commercial technologies to evaluate link alignment, performance and delivery of applications across the user cases studies in a rural environment.

8. Interim Report – Broadway Partners

This report presents the work completed so far by Broadway Partners (BP), it is intended as an interim report since technical issues and equipment availability problems meant that the networks were not built as early as planned in the original project plan.

BP is therefore, continuing their trials into the Phase 2 period for 2-3 months, at the end of which the final report will be presented.

9. Executive Summary

9.1. BP Approach

Broadway Partners is a network operator and ISP based in Liverpool and Glasgow. We have networks in Inverness-shire, Perth and Kinross, Ayrshire and the Isle of Arran, and also Monmouthshire in South Wales.

Our mission statement is to "connect the unconnected".

We are genuinely technology-agnostic and believe in practical and robust solutions driven by economics and accelerated progress for communities rather than let perfection be enemy of the good.

This philosophy has tested our technical capability over the years, most notably with our early ground-breaking work on low frequency Dynamic Spectrum in the TV White Space band and high frequency mesh technology in the 60GHz band.

9.2. Low Frequency Dynamic Spectrum

It is our view that spectrum is a finite, inexhaustible and extremely valuable resource.

Spectrum Sharing makes the most of that resource and is a well acknowledged requirement to deliver 5G long term. In 5G, sharing can be for seconds whilst an autonomous vehicle moves through an area, or for longer periods of time for various uses such as an event or concert.

TV White Space is a spectrum-sharing technology and operates in the 470-790MHz frequency range.

It is a fairly new / maturing technology and is almost tailor-made for a rural environment.

Low frequency radio works well in rural environments due to its propagation characteristics. With the ability to penetrate clutter it has obvious benefits over and above high frequency radio.

TVWS is unique in that it is the first spectrum to be managed by a geolocation database.

The spectrum is shared with primary users - Digital Terrestrial Television (DTT) and Program Makers and Special Event (PMSE) users.

The database is managed by Ofcom with rules to protect DTT and PMSE users from interference from White Space Devices (WSD).

Deploying WSDs is not widely understood with only a small handful of commercial operators with any experience. There are even fewer that have persevered with the technology from inception to the new modern devices, but I am proud to say Broadway has been one of them.

Shared Spectrum is a key component of 5G, and the most efficient models for predicting propagation to maximise spectrum efficiency should be utilised. If the regulation around shared spectrum is not efficient then devices will not be protected, or spectrum will be wasted in the future.

9.2.1. Questions - LFDS

Two Key Questions were posed:

- Question 1

Are current propagation models utilised in dynamic spectrum regulatory framework transferable to WSD planning and deployment?

To aid deployment -

- Do WSDs perform as the models predict?
- What is the best model?
- What terrain data is the most efficient?

- Question 2

Has TV White Space come of age? Can White Space technology be utilised now to deliver applications such as broadband and achieve modern performance standards?

The report sets out the work completed to determine the answers to the questions.

- See Section 8 for the detailed answer to Question 1
- See Section 9 for the detailed answer to Question 2

In summary:

Question 1

No, it would appear that Hata Extended with the suburban / urban clutter assumption does not transfer to good results when planning TVWS links. The best propagation model we found was Longley Rice with a Terrain 50 dataset.

Question 2

USO universally achievable in testing. TVWS is a good technology in a lot of areas for NGA speeds with 70Mbps achieved during testing.

9.3. 60GHz Mesh Technology

In the later part of 2018 Ofcom relaxed its regulation around the 60GHz band to enable point to multipoint deployments with higher power antenna gain.

60GHz spectrum is utilised for short distance, high speed communication. Ofcom is in the process of clearing higher frequency to enable more high-speed access specifically for 5G fixed wireless access.

60GHz technology has been utilised in the US and other countries in a point to multipoint scenario but not much is known about the mesh capabilities of 60GHz.

Furthermore, I do not believe a lot is known about the rural application of the technology.

Because of its propagation characteristics, most notably its oxygen absorption rate and susceptibility to clutter, it is questionable if the technology can usefully be utilised in a rural environment to deliver low latency, high speed performance – and Broadway has set out to answer that question.

9.3.1. Questions – 60 GHz

As with the Low Frequency Dynamic Spectrum, two key questions were posed:

- Question 1

Should 60GHz technology be considered at all for rural deployments?

- Question 2

Does new point to multipoint / mesh technology offer any benefits in a rural environment?

See Section 12 for the answers to these questions, but in summary;

- Question 1 - 60 GHz has a pivotal and complementary role in rural environments.
- Question 2 - Yes, there are NLOS and deployment benefits to 60GHz mesh.

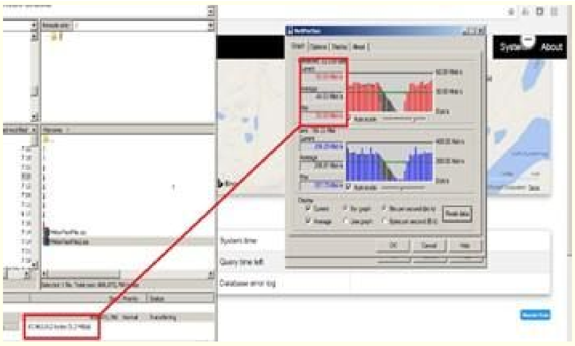
10. Dynamic Spectrum

Here we will attempt to answer the questions related to Dynamic Spectrum and TV White Space.

10.1. Hardware Selection Process

Prior to the pilot Broadway had been testing a new radio from Canadian firm [6 Harmonics](). The radio was capable of 3 x 8MHz contiguous channel aggregation – a total of 24MHz.

We tested the radio in a limited amount of deployments in Abriachan near Loch Ness in Scotland and achieved TCP NGA broadband speeds over long distance, non line of site (NLOS), which at the time had never been achieved with a WSD in the UK. We were convinced sustained NGA speeds, latency and jitter would be achievable with an even newer, smarter radio.



The next generation of device was capable of 32MHz contiguous aggregation, called the 5000 series. The 5000 has a geo-located base and client which means there are many deployment scenarios where the client can operate at higher power than a non-geolocated slave, which is very appealing.

As part of their preparation for the 5GRIT programme our colleagues at Quickline Communications had also engaged with 6 Harmonics and were in a more advanced stage of ordering in larger quantity. This meant that Broadway's order of a significant shipment might be delayed.

Broadway decided that instead of testing the same radio in much smaller scale we would consider a new supplier and purchase one 6 Harmonics radio for review and comparison.

The criteria for the new supplier was:

- Readiness to ship in dozens of units – many suppliers do "starter kits" which are essentially a point to point link, often built to order
- Minimum of 24MHz channel aggregation – from our initial testing we did not feel that smaller channel bandwidths were capable of more than 30Mbps in the most ideal conditions
- Modulation of MCS 7 capable – higher modulation is preferable for faster speeds
- Some evidence of capability to achieve over 30Mbps throughput
- Standard voltage PoE input (24/48v) for ease of integration

- No self-build or component installation – we did not want to buy a modem and then build a radio as we did not have time

Broadway consulted with leading WSD manufacturers in the US, France and China but only one could meet the criteria, which made the process very quick and clean. Most manufacturers at the time could only manage 1 x 8MHz channel but had an advanced development plan for aggregated channels – some contiguous, some non-contiguous.

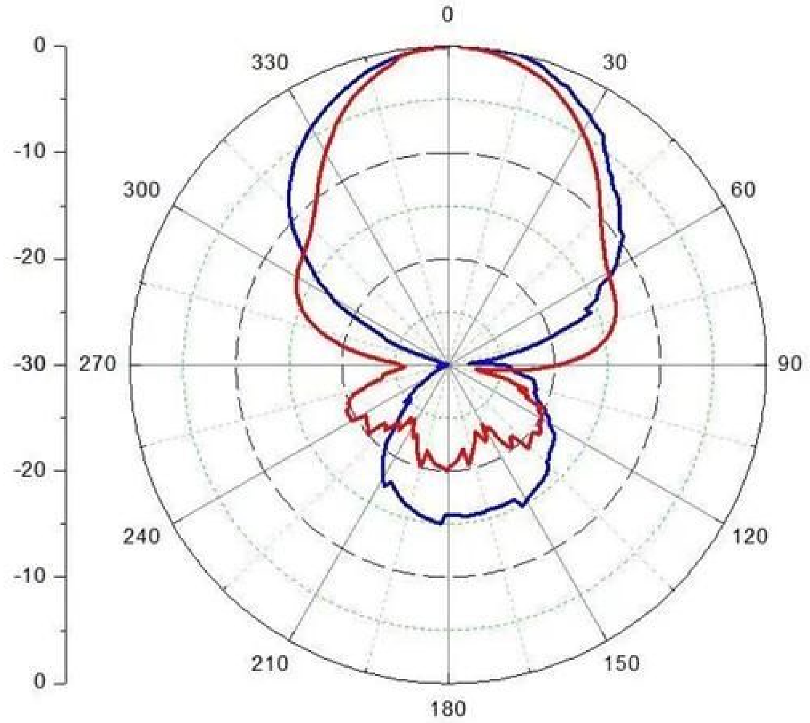
10.2. HuWoMobility Radio

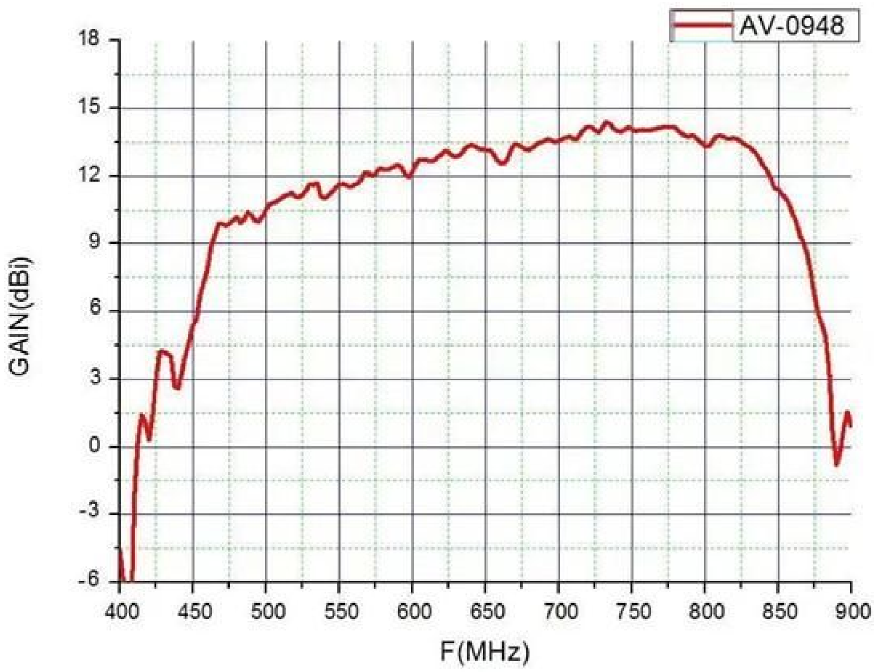
HuWoMobility iz based in San Francisco and produced the world's first 2x2 MIMO WSD.

- Their radio is called the HL3210.
- Max. Throughput: 300Mbps @ 40MHz
- Operating Bands: 470MHz - 790MHz
- MIMO: 2x2
- Channel Bandwidths: 6/8/12/16/1 8/24/30/32/36/40 MHz
- Modulations: OFDM: BPSK, QPSK, 16QAM, 64QAM
- Transmit Power: Max. 23dBm
- Power Supply: POE
- Lightning Protection: 6kV contact
- Water Resistance: IP65
- Security: WPA-PSK/WPA2-PSK, MAC Address
- Access Control (ACL)

10.2.1. Antenna Pattern and Gain

The antenna is approximately 60 degree directional with a maximum gain of 14dbi. The antenna gains around 5db between 470 and 790 which we had to take into account when calculating the EIRP limit in testing to comply with maximum power limits of WSDs.

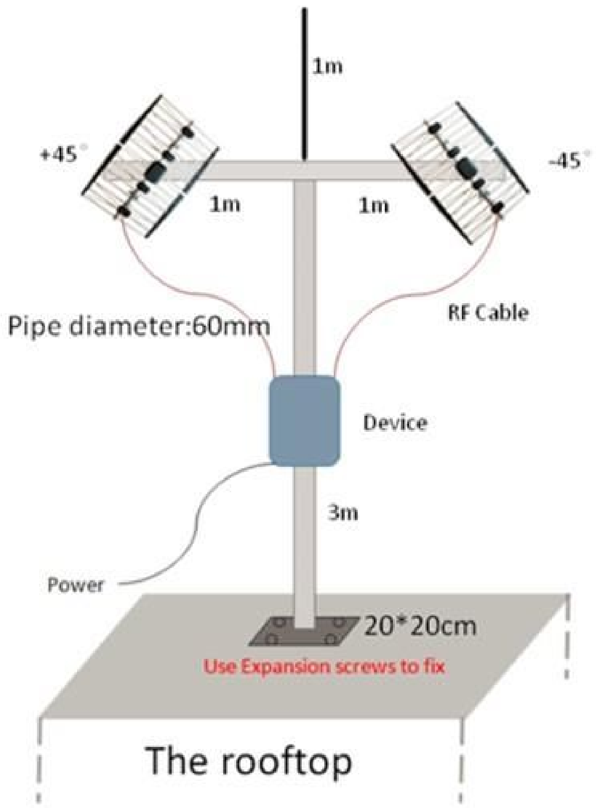




10.2.2. Antenna Mounting Configuration

The antenna configuration is quite unique utilising 2 flat Yagi style antenna at 45 degree angles.

If the antenna is not at 45 degrees and approximately 1 metre apart the MIMO capability will not work for sustained periods of time.



10.3. 6 Harmonics

Details of the 6 Harmonics radio have been documented in other work packs. For reference the link for the radio can be found here for the manufacturers spec. This radio is actually the 4000 but the only major difference is the addition of the GPS module.

http://www.6harmonics.com/wp-content/uploads/2017/02/GWS-4000-Series-Datasheet-FCC-certified-July-2016.pdf

SL14175A 11dBi Directional

Item Name	Specification
Electrical Parameter	
Frequency Range (MHz)	470-860
VSWR	≤1.5
Input Impedance(Ω)	50
Gain(dBi)	10
Polarization	Vertical or Horizontal
Horizontal Plane Θ_{HP} (°)	65±10
Vertical Plane Θ_{HP} (°)	50
Front to Back Ratio (dB)	12
Maximum Input Power(W)	50W
Connector Type	N -Female
Lightning Protection	DC ground
Other Parameter	
Radome material	ABS
Working Temperature(℃)	-40~+60
Dimension (mm)	1200×350×50
Weight(Kg)	2

10.4. Initial Testing Prior to Purchase of HuWoMobility Radio

Having already experienced good performance from the 6H 4000 and due to the fact we were only purchasing one radio we felt it low risk to acquire a single 5000 unit.

For any brand-new equipment manufacturers we always initiate a light weight test regime to confirm the radio lives up to expectations and performs as expected.

We have tested many different devices in the past and invested heavily in R&D. Our experience often differs between manufacturer claims and the reality of deployment. This is usually because the manufacturer tests in a lab under perfect conditions.

It is my opinion that if the radio is going to perform you will see signs of it delivering to at least 75% of expected value within four hours of establishing the first link in good conditions.

If the radio is not performing as expected, then a thorough review of the deployment should take place with the manufacturer before investing more time and resource.

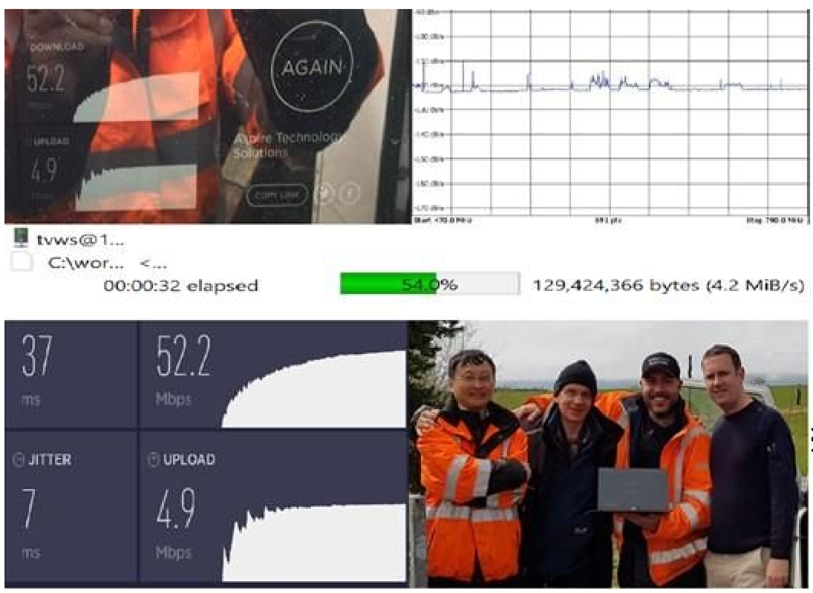
We set up a temporary deployment at an area known internally as “The Proving Ground” situated in Dores, Inverness-shire and met a representative of HuWo Mobility who flew in from California with a pair of radios. The site is ideal because of the availability of high power channels at the top end of the permissible range.

The good availability of channels is due to the advanced progress of the [Arqiva DTT clearance]() programme. At 20 metres even with a high emitting device the radio can operate at a full 36dbm EIRP (4W) over a minimum of four contiguous channels. The site features flat areas as well as hills, water and forestry.

The test focused on orientation initially – going through the setup, performing firmware upgrades, building the platform, understanding steelwork requirements, understanding lessons learnt from the manufacturer and the DB integration intricacies.

The tests are admittedly basic and involve 2 short 300 metre and 2 long tests at 1km both non-line of site (NLOS) and line of site (LOS).

The initial tests conclusively revealed that the radio was capable at long distance NLOS and was performing to expected performance with good TCP throughput and so was worthy of



further investment and investigation.

11. Dynamic Spectrum Management Database

Ofcom manages access to the 470MHz to 790MHz spectrum through a database called a Dynamic Spectrum Management Database.

Access to the database is managed through authorised representatives.

The database can be accessed through 3rd parties such as Fair Spectrum and Nominet respectively:

https://www.fairspectrum.com/

https://www.nominet.uk/spectrum-management/

Both database providers have different commercial models and some radio manufacturers have agreements direct with both for easier integration.

11.1. Method to Access DB - Temporary Installations and Test Sites

In order to test the WSD propagation we needed to have a temporary internet connection to access the database.

In Scotland we overcame the problem by supplying temporary connectivity via a 5GHz sector from our existing networks. There is often no mobile reception where our networks are situated.

The links were not capable of providing fast internet so throughput testing during propagation testing was not an option, but we could query the DB and maintain contact.

In Cheshire we utilised a 3G modem.

12. Dynamic Spectrum - Answering Question 1

Are current propagation models utilised in dynamic spectrum regulatory framework transferable to WSD planning and deployment?

To aid deployment -

- What is the best model?
- Do WSDs perform as the models predict?
- What terrain data is the most efficient?

12.1. Current Propagation Model in Regulatory Framework

PMSE is a term used to denote equipment used for broadcasting – for example wireless microphones, talkback and audio links.

We will take the propagation model used for determining PMSE interference from a WSD to form a baseline comparison with another propagation model.

12.2. PMSE Protection - Background

Interference from a PMSE device is not calculated for the WSD. The interference is "one way" so far as the protection calculation is concerned.

Ofcom describe the protection rule in very clear terms – "The WSD interfering signal should be sufficiently far below the PMSE signal at the same frequencies as not to cause audio degradation."

The WSD operating in the same band as a PMSE user will increase noise and therefore the signal to noise ratio will decrease for the PMSE user. To calculate the increased noise there has to be some calculation to ascertain what the increase will be and a limit for degradation.

Having studied the Ofcom documentation Implementing TV White Spaces and Annexes released in 2015 following an initial consultation in 2013, the propagation model utilised for PMSE interference calculations is Hata Extended utilising Urban and Suburban Clutter only.

12.3. Model Explanations

12.3.1. Hata Extended Model (30-3000 MHz)

This model is compatible with SEAMCAT (CEPT). It does not consider the terrain, and only considers the Tx and Rx heights. Clutter can be utilised in the propagation path but it does not take into account terrain and has free space path loss characteristics. In this case we will assume suburban clutter.

12.3.2. Comparison Model Selection

Dr Oliver Holland from Kings College has utilised the Longley-Rice model in his calculations in previous work packs for the 5GRIT project.

The Dynamic Spectrum Alliance make a strong case for Longley-Rice in their Suggested Technical Rules and Regulations for the Use of Television White Spaces documentation.

12.3.3. Longley-Rice ITM NTIA (20 MHz – 20 GHz)

The Irregular Terrain Model provides propagation models used to make prediction of radio field strength for broadcast in the range 20MHz – 20 GHz. The model can take into account terrain data in the Fresnel path which crucially Hata Extended does not.

12.4. Terrain Data

We have access to two free data sets of 50 and 30 metre resolution. We also have a 2M 2016 Photogrammetric high-resolution dataset.

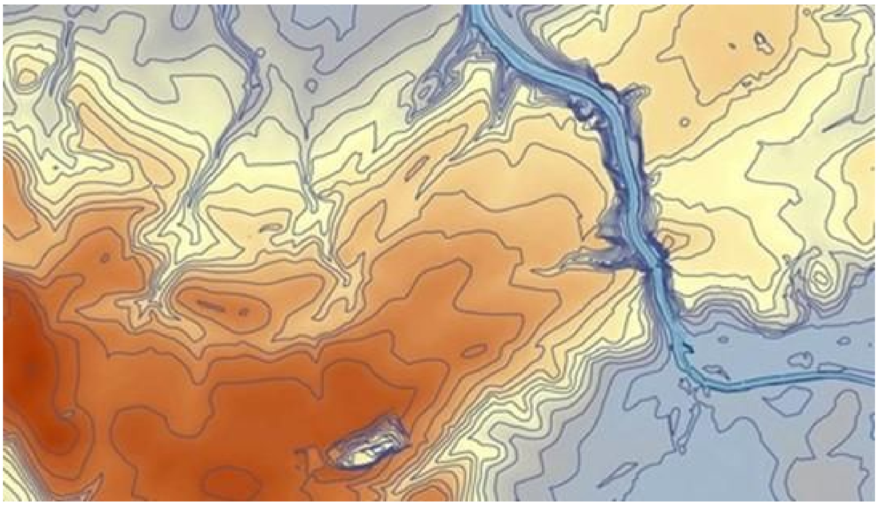
12.4.1. Note on Terrain and Clutter Data Manipulation

We discovered that manipulating raw terrain and clutter data is not a trivial task, is extremely time consuming from a computer processing perspective and can require multiple separate software packages to achieve a desired result.

As with propagation modelling, a single setting out of potentially dozens can cause discrepancies with the data. The team decided to go with the three most reliable options following extensive experimentation.

12.4.2. 50 Metre OS Terrain 50 data

The OS Terrain 50 was composed from the July 2017 dataset. OS Terrain 50 is free to view, download and use for commercial, education and personal purposes.



12.4.3. 30 Metre SRTM 1arc second data.

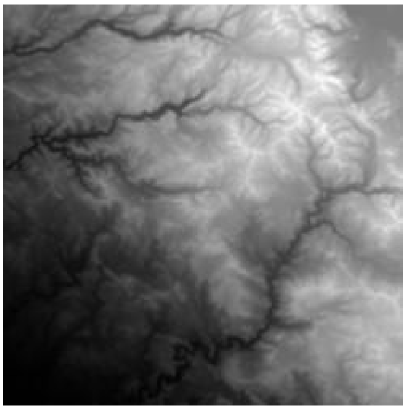
The source data for the 30 metre DTM is https://lpdaac.usgs.gov/node/527 from the Space Shuttle Endeavour mission which flew for 11 days in February 2000.

It is free to use like the OS terrain 50 dataset but is a slightly higher resolution. As it is capturing terrain data and not clutter data then the age is of less consequence.

Citation

PI Name: Michael Kobrick, Robert Crippen

DOI: 10.5067/MEaSUREs/SRTM/SRTMGL1.003

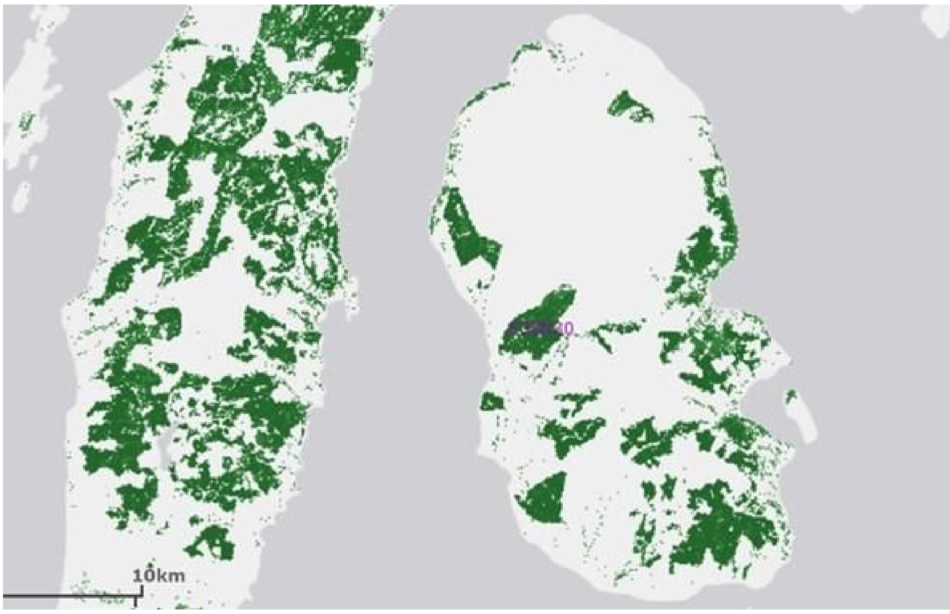


12.5. Clutter

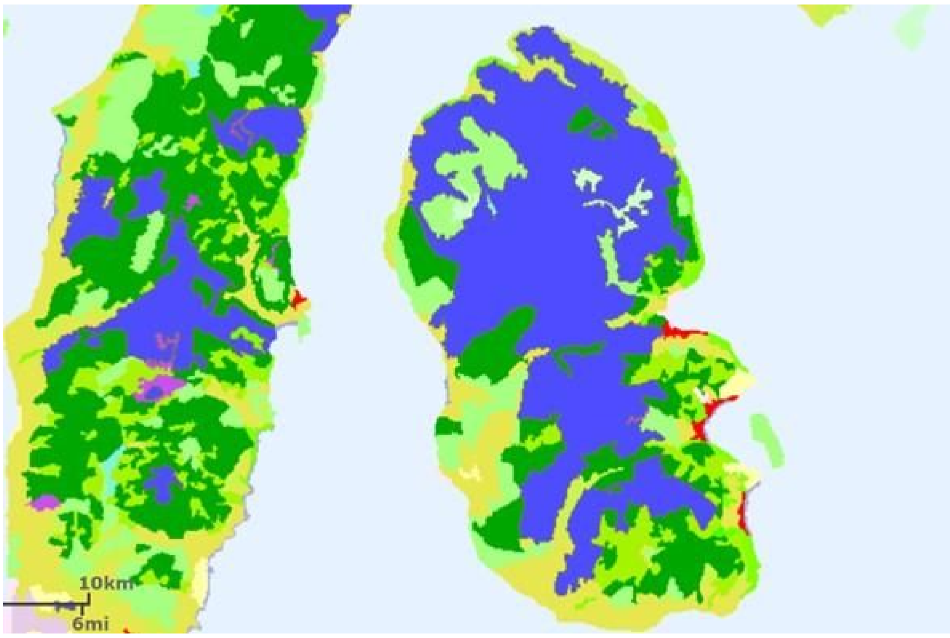
We utilised two different types of clutter and a test utilising no clutter.

Tree data was captured by the European Space Agency in 20m resolution. It is available from ESA's Copernicus website https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/2015 . We resampled this to match the SRTM at 30m. The data showed a value between 0-100 for tree cover density. We created a binary split between trees and no trees (0-9 no trees, 10-100 trees). With the tree/no tree layer we assigned a height value of 10m for use in ICS telecom.

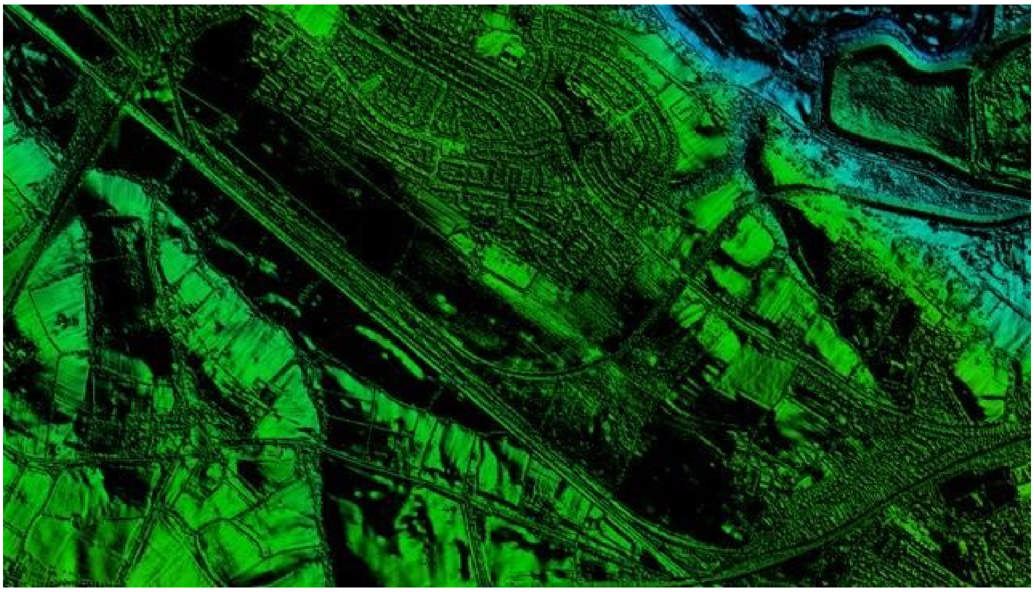
We choose trees as the primary clutter type because in rural environments it is the most likely clutter you will encounter. The tree data was captured between 2012 and 2015. We are utilising the most recent data from 2015.



For the 50 metre data we utilised Corine Land Cover Data again from the Copernicus website. This is quite a comprehensive clutter dataset containing many different types of clutter including trees and forests but with all of the other clutter types including open.



The 2 metre data is from 2016 and supplied by Blue Sky World. It is not free and is a 2M Photogrammetric high resolution dataset. As you can see below the resolution is extremely detailed with single trees and buildings visible.



12.6. Terrain Data, Clutter and Propagation Model Summary

Name	Key
30 Hata Tree	Copernicus 30 meter data with 30 meter tree cover clutter with simulation carried out using Okumura Hata Extended model
30 Longley Tree	Copernicus 30 meter data with 30 meter tree cover clutter with simulation carried out using Longley Rice model (IRTM)
30 Hata	Copernicus 30 meter data with simulation carried out using Okumura Hata Extended model - NO CLUTTER
30 Longley	Copernicus 30 meter data with simulation carried out using Longley Rice Extended model - NO CLUTTER
50 Hata Corine	OS Terrain 50 meter data with Corine clutter layer with simulation carried out using Okumura Hata Extended model
50 Longley Corine	OS Terrain 50 meter data with Corine clutter layer with simulation carried out using Longley Rice model (IRTM)
50 Hata	OS Terrain 50 meter data with simulation carried out using Okumura Hata Extended model - NO CLUTTER
50 Longley	OS Terrain 50 meter data with simulation carried out using Longley Rice Extended model - NO CLUTTER
2m Hata	2M Photogrammetric DSM with Okumura Hata Extended model
2m Longley	2M Photogrammetric DSM with Longley Rice model

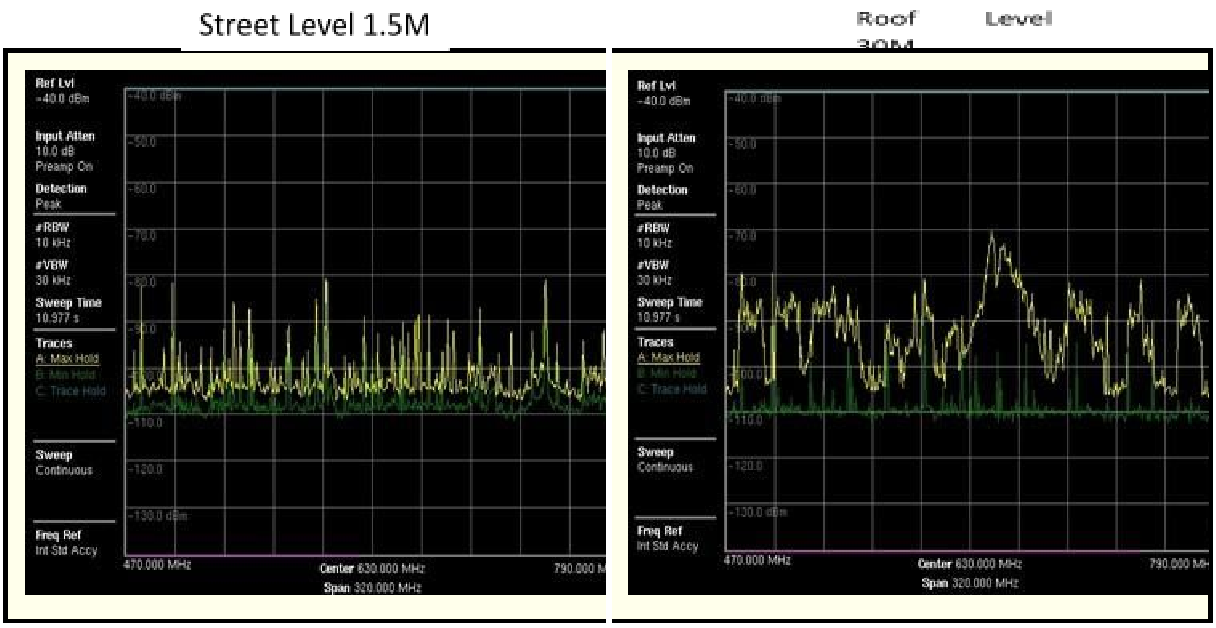
13. Testing

13.1. Test Equipment

Each test was conducted at 1.5 metres AGL utilising a 1.5 metre non-penetrating mount at each end of the link for simple transportation. Power was supplied by generator, invertor or battery power bank.

13.2. Transmission Height and Transmit Power

During testing we observed that with increased height usually comes increased noise. It is no coincidence that the reason people put TV antennas on the roof of their property is because that is where the best reception is. Below is an example from street level at our Liverpool office compared to the roof approximately 30 metres where the local DTT usage is very clear.



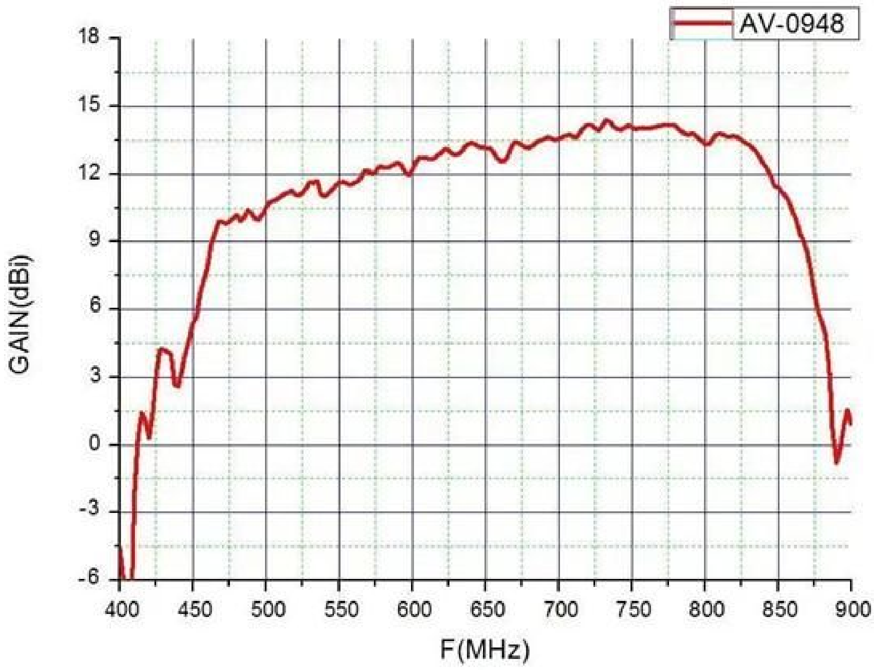
13.3. White Space Database Planning Intricacies

TVWS databases on the whole allow for greater power at lower antenna height (AGL).

The minimum power output from the radio is 15dbm.

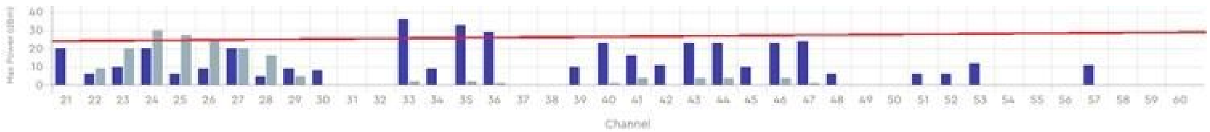
With the manufacturer recommended antenna attached, any channel under 24dbm at 470 rising to around 29dbm EIRP cannot be utilised at the higher end of the band due to the antenna gain performance.

A smaller gain antenna could be utilised and we are keen to explore the impact of smaller antenna in the future. We would also like to explore a standard Yagi rather than a flat antenna.

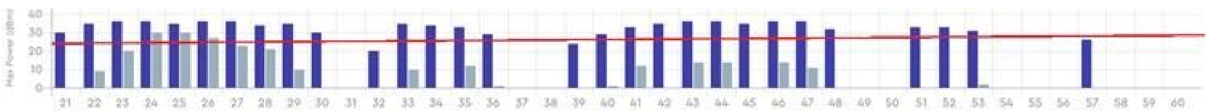


Utilising [Nominet's Wave DB Explorer]() tool, it is simple to show what this means to the planning process.

In this example taken at 30 metres AGL the blue channels below the red line are not usable for this test because by default the radio will over power the permitted transmit power for the location apart from channels 33, 35 and 36.



At 1.5 metres AGL there is more selection for the same area.



Another fairly common phenomenon we found is the detail in which a link can be affected by location.

A cursory glance at channel availability can mislead a designer to think there are available channels.

In fact the location could be as little as 25-50 metres out and can drastically affect the link. If you are using Google Earth to get a bearing for example and are not fully “zoomed” into an area this is very easy to do.

Limiting the physical height of the base station can help to smooth this effect out slightly and is a deployment technique we have found useful in the past. I am not certain if the terrain resolution (100m x 100m pixels) could be increased to reduce the aggressiveness of this type of behaviour but we will not focus on this.

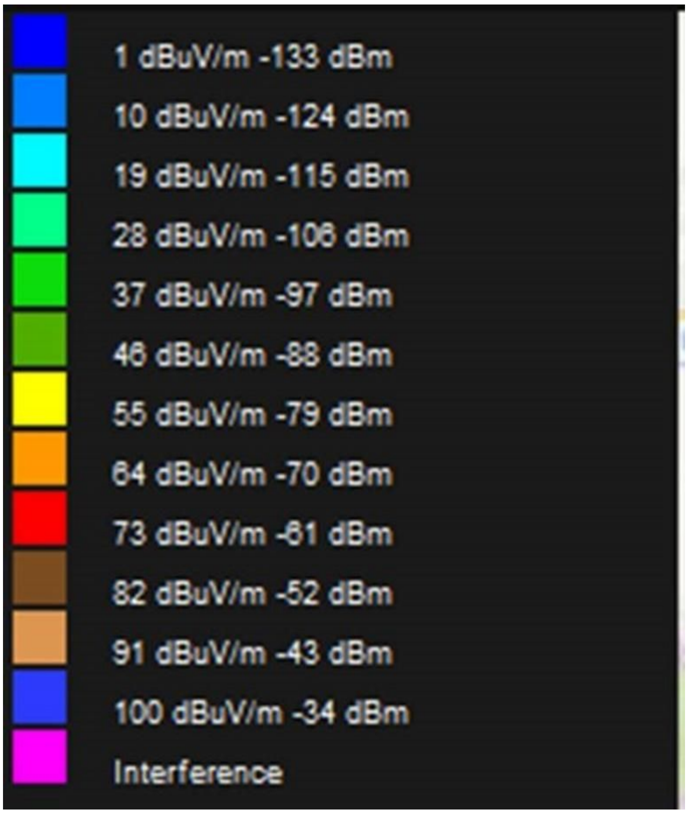
Counterintuitively, every so often the device power in certain channels will increase the higher the antenna is. At 30 metres channel 33 looks like it could transmit at around 29dBm EIRP and there are a few other non-viable but prominent channels.

At 5 metres, channel 33 does not look viable and the rest of the channel power has diminished across the range.

I believe that this a symptom of a propagation calculation. I do not know if the prorogation characteristic utilised by the database casts a shadow underneath the WSD transmission point that moves out from the transmission point and if this is calculated. It is not possible to test down tilt of the antenna to determine if this changes the behaviour.

13.4. Simulation - ATDI Configuration

Each test area was simulated at 1.5 metres with 12dBi antenna gain.



13.4.1. Longley Rice

All clutter for the Longley Rice model has been mapped to default values.

Clutter code		Name	Attenuation (dB)		Clutter height	Reflection coef. (0-1)	Erlang/km2	Surface factor	Diffraction factor	Station/km2	Stddev (dB)
0		open	0.0	0.0	1	0.250	1.0000	1.000	1.00	1.000	1.00
1		village	0.0	0.0	6	0.300	1.0000	1.000	1.00	1.000	1.00
2		suburban	0.0	0.0	10	0.300	1.0000	1.000	1.00	1.000	1.00
3		urban	0.0	0.0	15	0.300	1.0000	1.000	1.00	1.000	1.00
4		dense urban	0.0	0.0	20	0.300	1.0000	1.000	1.00	1.000	1.00
5		forest	0.0	0.0	12	0.111	1.0000	1.000	1.00	1.000	1.00
6		hydro	0.0	0.0	0	0.020	1.0000	1.000	1.00	1.000	1.00
7		high urban	0.0	0.0	35	0.300	1.0000	1.000	1.00	1.000	1.00
8		park/wood	0.0	0.0	4	0.080	1.0000	1.000	1.00	1.000	1.00
9 *		roof - building	auto	0.0	0	0.252	1.0000	1.000	1.00	1.000	1.00
10		rail	0.0	0.0	0	0.058	1.0000	1.000	1.00	1.000	1.00
11		road	0.0	0.0	0	0.058	1.0000	1.000	1.00	1.000	1.00
12		airport	0.0	0.0	0	0.300	1.0000	1.000	1.00	1.000	1.00
13		Tunnel	0.0	0.0	0	0.300	1.0000	1.000	1.00	1.000	1.00
14		open rural	0.0	0.0	0	0.300	1.0000	1.000	1.00	1.000	1.00
15 *		b-plaster	auto	0.0	0	0.309	1.0000	1.000	1.00	1.000	1.00
16 *		b-brick	auto	0.0	0	0.444	1.0000	1.000	1.00	1.000	1.00
17 *		b-glass	auto	0.0	0	0.040	1.0000	1.000	1.00	1.000	1.00
18 *		b-wood	auto	0.0	0	0.370	1.0000	1.000	1.00	1.000	1.00
19 **		border	0.0	0.0	0	0.300	1.0000	1.000	1.00	1.000	1.00

13.4.2. HATA Extended

All clutter in the HATA extended model has been mapped to suburban 10 metre. ATDI allows for clutter types which can be mapped to different values. By setting all of the clutter types to Suburban we can test the HATA Extended model with similar settings to the Ofcom PMSE interference model.

Clutter code	Name	Area
0	open	Rural (0)
1	village	Suburban (1)
2	suburban	Suburban (1)
3	urban	Urban (2)
4	dense urban	Metro (3)
5	forest	Rural (0)
6	hydro	Rural (0)
7	high urban	Urban (2)
8	park/wood	Rural (0)
9	building	Metro (3)
10	rail	Rural (0)
11	road	Rural (0)
12	airport	Rural (0)
13	Tunnel	Rural (0)
14	open rural	Rural (0)
15	b-plaster	Rural (0)
16	b-brick	Rural (0)
17	b-glass	Rural (0)
18	b-wood	Rural (0)
19	border	Rural (0)

14. Test Locations

14.1. Isle of Arran, North Ayrshire

The Isle of Arran is known as ‘Scotland in Miniature’ due to its mountainous northern regions and low lying Southern regions.

The island is close to Kintyre and is quite deserted in the Northern areas with convenient places to pull in and test.

Broadway Partners began testing TVWS there is 2016 and we believe it is the site of the first live commercial deployment of TV White Space.

14.2. Loch Leven, Perth and Kinross

Mixed Terrain Environment

Whilst the area is rural there is a good mix of different terrain types – from small built-up areas to open water and hills.

Broadway started operating there in 2018 and now cover around 100 square kilometres of territory to the west of Kinross.

14.3. Delamere Forest, Cheshire

Delamere Forest is easy to get around due to the excellent and highly maintained walking and cycling trails.

The forest has dense areas as well as woodland areas with some reasonably flat and long stretches. This was important because the test is to determine clutter impact rather than terrain. Finding a local forest that was flat was extremely challenging.

This test was incorporated to understand foliage attenuation following initial results from Arran and Loch Leven.

14.4. Future Areas for Further Investigation

We would like to test more areas. At the moment we are mobilising to deploy again.

14.4.1. Inverness-shire, Loch Ness

Broadway have been operating a network in Loch Ness for 2 years. It is very hilly with clean air and we would like to continue testing in the next few months.

14.5. Note on Propagation Test Results

The results have not been fully ratified in part due to complications during the capture phase of radio testing and the concurrency of the 60GHz testing programme. The results will be subject to internal review and consultation with ATDI. The final results will be published at the end of the project extension in May and any findings documented.

Channel Availability Summary

Central freq. [MHz]	474	482	490	498	506	514	522	530	538	546	554
Channel number	21	22	23	24	25	26	27	28	29	30	31
Kintyre and Arran	20	-25	29	29	-25	29	32	-20	27	27	27
Perth and Kinross	18	30	36	17	36	36	17	36	14	23	15
Cheshire	20	30	32	31	29	28	26	25	17	8	-46
Min Transmit Power + Antenna	Min 27dBm EIRP										

Central freq. [MHz]	562	570	578	586	594	602	610	618	626	634	642	650	658	666	674
Channel number	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
Kintyre and Arran	36	36	36	33	25	15	-980	15	25	33	36	36	36	36	36
Perth and Kinross	-2	36	-2	-2	25	15	-980	15	12	10	36	10	10	36	10
Cheshire	8	17	25	23	14	-40	-980	15	21	31	21	21	32	20	20
Min Transmit Power + Antenna	Min 29dBm EIRP														

Central freq. [MHz]	682	690	698	706	714	722	730	738	746	754	762	770	778	786
Channel number	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Kintyre and Arran	36	36	36	36	36	36	36	36	27	36	36	36	36	-980
Perth and Kinross	10	-28	-14	35	-980	36	-11	-15	-28	-17	-11	-15	36	-980
Cheshire	23	13	-41	-40	14	23	14	-39	-46	8	15	-39	-39	-980
Min Transmit Power + Antenna	Min 30dBm EIRP													

Available channel

EIRP unavailable channel

Database protected channel

14.6. Terrain Data, Clutter and Propagation Model Summary

Name	Key
30 Hata Tree	Copernicus 30 meter data with 30 meter tree cover clutter with simulation carried out using Okumura Hata Extended model
30 Longley Tree	Copernicus 30 meter data with 30 meter tree cover clutter with simulation carried out using Longley Rice model (IRTM)
30 Hata	Copernicus 30 meter data with simulation carried out using Okumura Hata Extended model - NO CLUTTER
30 Longley	Copernicus 30 meter data with simulation carried out using Longley Rice Extended model - NO CLUTTER
50 Hata Corine	OS Terrain 50 meter data with Corine clutter layer with simulation carried out using Okumura Hata Extended model
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50 Hata	OS Terrain 50 meter data with simulation carried out using Okumura Hata Extended model - NO CLUTTER
50 Longley	OS Terrain 50 meter data with simulation carried out using Longley Rice Extended model - NO CLUTTER
2m Hata	2M Photogrammetric DSM with Okumura Hata Extended model
2m Longley	2M Photogrammetric DSM with Longley Rice model

Reminder –

All Hata clutter is mapped to suburban.

All Longley clutter is mapped to the correct code.

14.7. Isle of Arran

Base station WSD located in Grogport, Kintyre peninsular directly facing Isle of Arran.

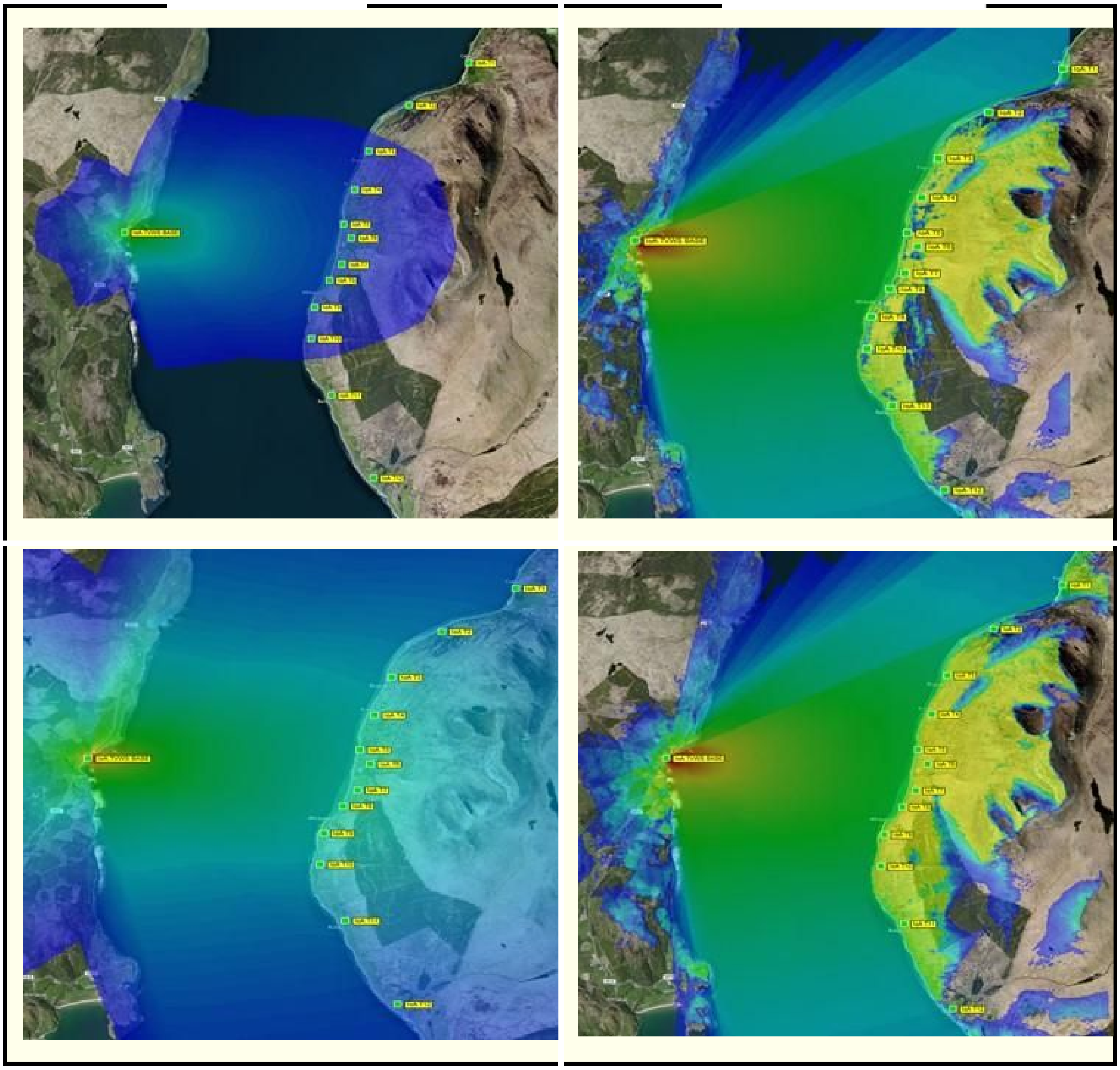
Base Details	IoA TVWS Base
Lat	[redacted]
Lon	[redacted]
Channel	52
Frequency	718-726
Power EIRP	30dbm
Height	1.5m
Azimuth	90
Tilt	0
Receive Antenna	1.5 M
Receive Gain	12dBi

14.7.1. Isle of Arran Propagation Models and Test Results

14.7.1.1 30 Metre Propagation Coverage Maps

30 Hata Tree

30 Longley Tree



30 Hata

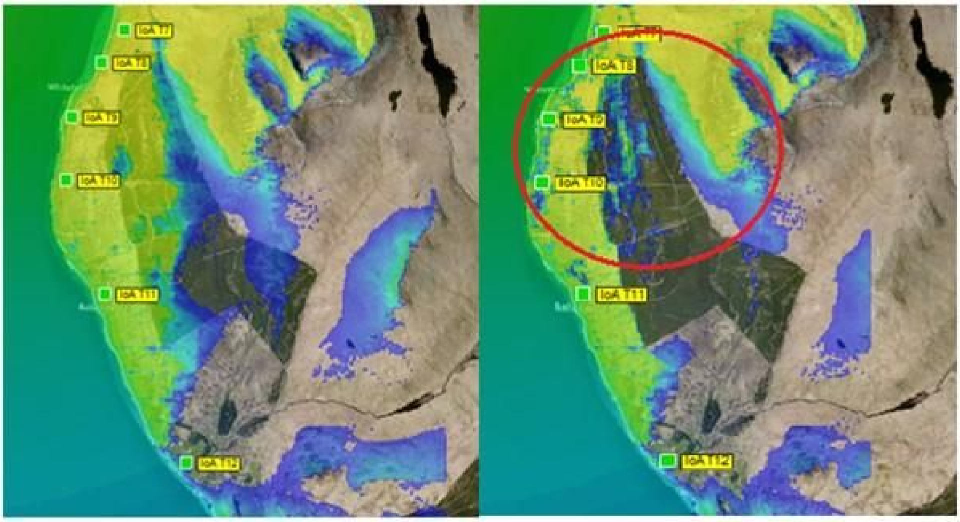
30 Longley

14.7.1.2 30 Metre Test Results

30 Meter Test Data				Terrain and Clutter Model		Terrain Only		Test Results
Call Signs	Distance Meters	Long	Lat	30 Hata Tree	30 Longley Tree	30 Hata	30 Longley	Actual RSSI
IoA T1	11109.08	[redacted]	[redacted]	No Signal	-92	-110	-97	No Signal
IoA T2	9007.7	[redacted]	[redacted]	No Signal	No Signal	-106	-64	No Signal
IoA T3	7418.92	[redacted]	[redacted]	-120	-64	-102	-67	-65
IoA T4	6748.67	[redacted]	[redacted]	-117	-59	-99	-59	-53
IoA T5	6304.57	[redacted]	[redacted]	-115	-63	-97	-70	-67
IoA T6	6512.49	[redacted]	[redacted]	-115	-58	-97	-58	-46
IoA T7	6313.41	[redacted]	[redacted]	-115	-58	-97	-58	-48
IoA T8	6046.69	[redacted]	[redacted]	-115	-73	-97	-73	-69
IoA T9	5894.06	[redacted]	[redacted]	-116	-68	-98	-64	-60
IoA T10	6225.7	[redacted]	[redacted]	-119	-62	-101	-62	-59
IoA T11	7655.88	[redacted]	[redacted]	No Signal	-66	-107	-66	-70
IoA T12	10204.1	[redacted]	[redacted]	No Signal	No Signal	-114	No Signal	no signal

With the 30 Hata Tree model, by assigning the same clutter code to all types of clutter, the effect is a uniform antenna pattern. When you remove the clutter layer the model stops working entirely and you end up with a free space path loss type model because there is no terrain variable.

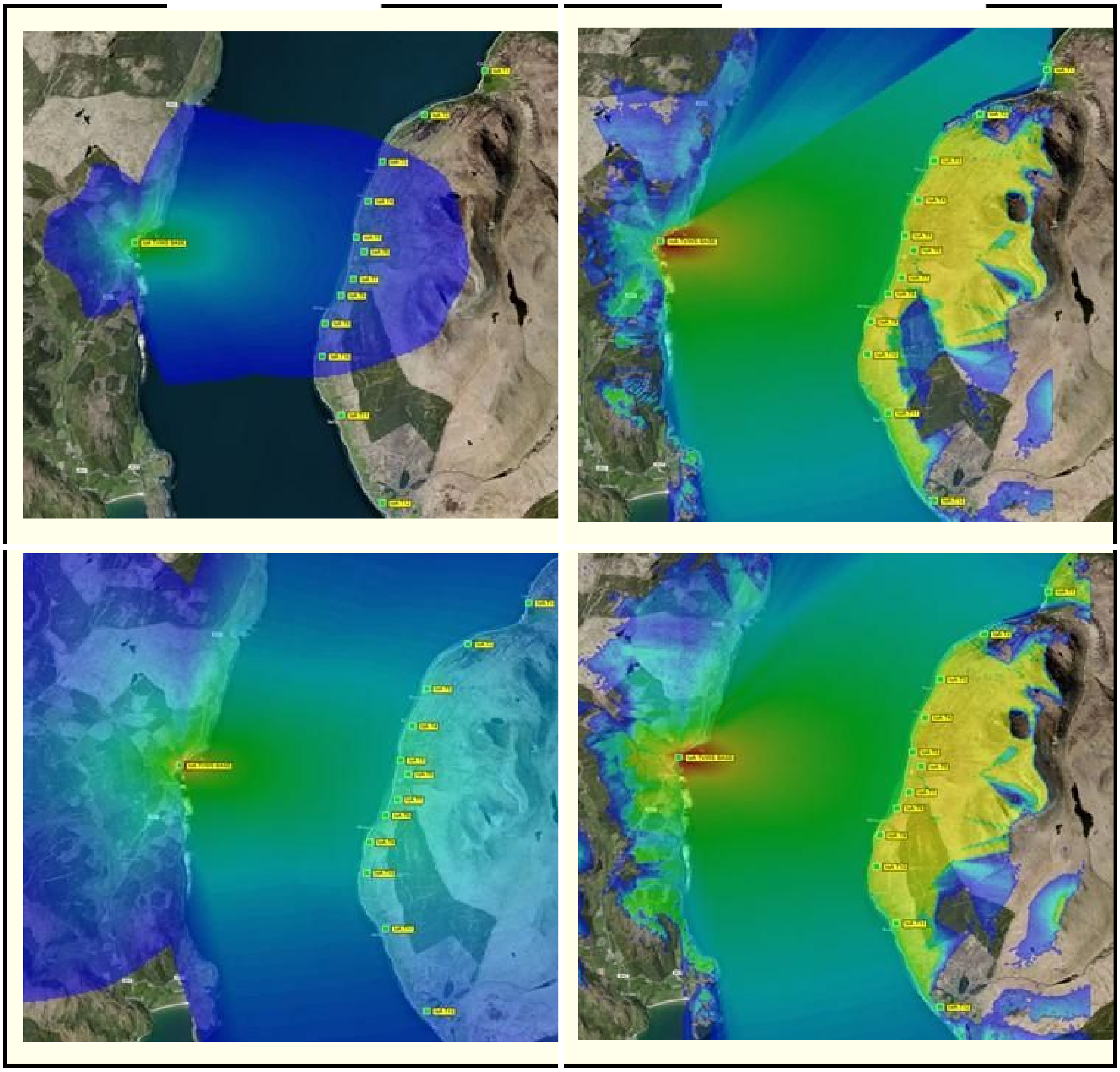
With the Longley models you can see the effect of clutter on the propagation model at the South end of the image very clearly. As the radio meets trees it attenuates and stops the propagation.



By enlarging, the most accurate results appeared to be 30 Longley Tree with neither Hata model particularly close to matching test results.

14.7.1.3 50 Metre Propagation Coverage Maps

50 Hata Corine | 50 Longley Corine



50 Hata | 50 Longley

14.7.1.4 50 Metre Test Results

50 Meter Test Data				Terrain and Clutter Model		Terrain Model Only		Test Results
Call Sign	Distance Meters	Long	Lat	50 Hata Corine	50 Longley Corine	50 Hata	50 Longley	Actual RSSI
IoA T1	11109.08	[redacted]		No Signal	-88	-110	-88	No Signal
IoA T2	9007.7	[redacted]		No Signal	-99	-106	-95	No Signal
IoA T3	7418.92	[redacted]		-120	-70	-102	-65	-65
IoA T4	6748.67	[redacted]		-117	-59	-99	-59	-53
IoA T5	6304.57	[redacted]		-115	-63	-97	-63	-67
IoA T6	6512.49	[redacted]		-115	-58	-97	-58	-46
IoA T7	6313.41	[redacted]		-115	-58	-97	-58	-48
IoA T8	6046.69	[redacted]		-115	-71	-97	-71	-69
IoA T9	5894.06	[redacted]		-116	-66	-98	-66	-60
IoA T10	6225.7	[redacted]		-119	-62	-101	-62	-59
IoA T11	7655.88	[redacted]		No Signal	-66	-107	-66	-70
IoA T12	10204.1	[redacted]		No Signal	No Signal	-114	No Signal	no signal

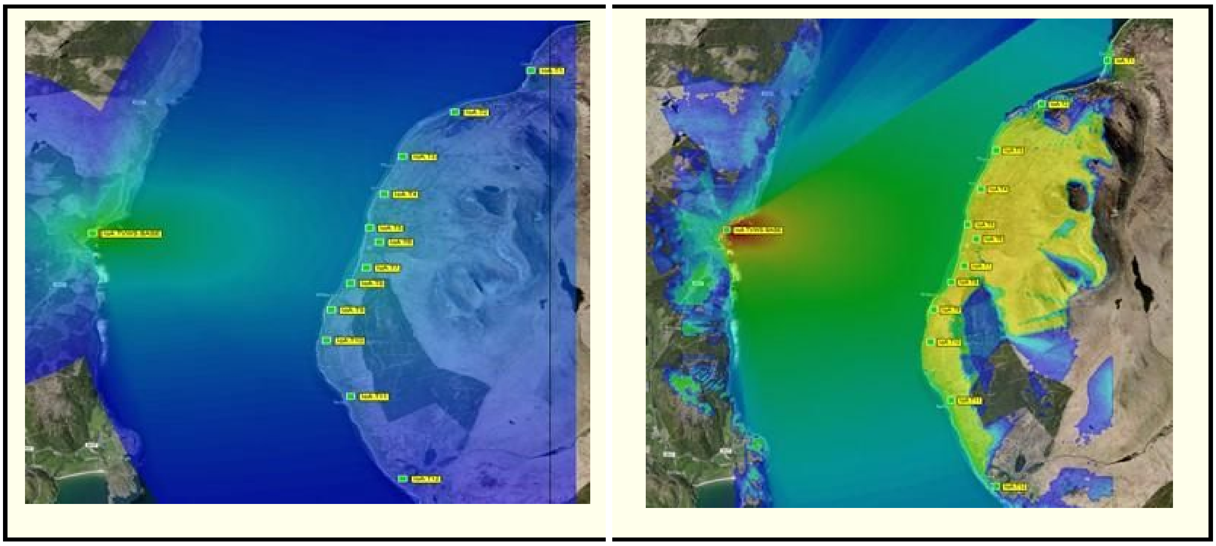
No resemblance to results from either Hata model.

Almost identical performance from the 50 Longley-Corine data and the 50 Longley data. The best model was chosen as 50 Longley-Corine because of the marginal attenuation detected at IoA T2 which we feel could be caused by a small coppice of trees pictured below.

Both Longley models predicted marginal links at IoA T1, T2 and T12 which was correct.

14.7.1.5 2 Metre Propagation Coverage Maps

2M Hata 2M Longley



14.7.1.6 2 Metre Test Results

2 Meter Test Data			DSM		Test Results	Link
Call Sign	Distance Meters	Long	Lat	2m Hata	2m Longley	Actual RSSI
IoA T1	11109.08	[redacted]		-116	-92	No Signal
IoA T2	9007.7			-112	-70	No Signal
IoA T3	7418.92			-108	-72	-65
IoA T4	6748.67			-105	-65	-53
IoA T5	6304.57			-103	-76	-67
IoA T6	6512.49			-103	-64	-46
IoA T7	6313.41			-103	-64	-48
IoA T8	6046.69			-103	-76	-69
IoA T9	5894.06			-104	-71	-60
IoA T10	6225.7			-107	-68	-59
IoA T11	7655.88			-113	-72	-70
IoA T12	10204.1			-120	No Signal	no signal

The 2M Longley results are fairly accurate apart from IoA T2.

14.7.2. Isle of Arran Summary

Recommended Model Comparison							
Call Sign	Distance Meters	Long	Lat	30 Longley Tree	50 Longley Corine	2m Longley	Actual RSSI
IoA T1	11109.08	[redacted]		-92	-88	-92	No Signal
IoA T2	9007.7			No Signal	-99	-70	No Signal
IoA T3	7418.92			-64	-70	-72	-65
IoA T4	6748.67			-59	-59	-65	-53
IoA T5	6304.57			-63	-63	-76	-67
IoA T6	6512.49			-58	-58	-64	-46
IoA T7	6313.41			-58	-58	-64	-48
IoA T8	6046.69			-73	-71	-76	-69
IoA T9	5894.06			-68	-66	-71	-60
IoA T10	6225.7			-62	-62	-68	-59
IoA T11	7655.88			-66	-66	-72	-70
IoA T12	10204.1			No Signal	No Signal	No Signal	no signal

On balance the best propagation model in this scenario is 50 Longley-Corine.

What was surprising was the excellent receive strength of the radio at IoA T6 and T7. This was clear LOS from the base station to the client device and the water does not appear to be causing much, if any, attenuation. It would be interesting to see if that remains in choppy weather conditions as the sea was very still during the test period.

One working theory is that the water could be causing multipath which the MIMO feature of the radio could be benefiting from.

A further test from inside the forest at the south end of the model would be beneficial to determine the effect of attenuation from clutter.

A further test with a single antenna in similar weather conditions (or with MIMO disabled) would help to explain the receive strength. Or we could test the 6H radio in the same location.

There are question marks over the 2M data results which will be investigated in the next few months especially for the Hata model.

14.8. Perth and Kinross Propagation Models and Test Results

Base station located near Loch Leven.

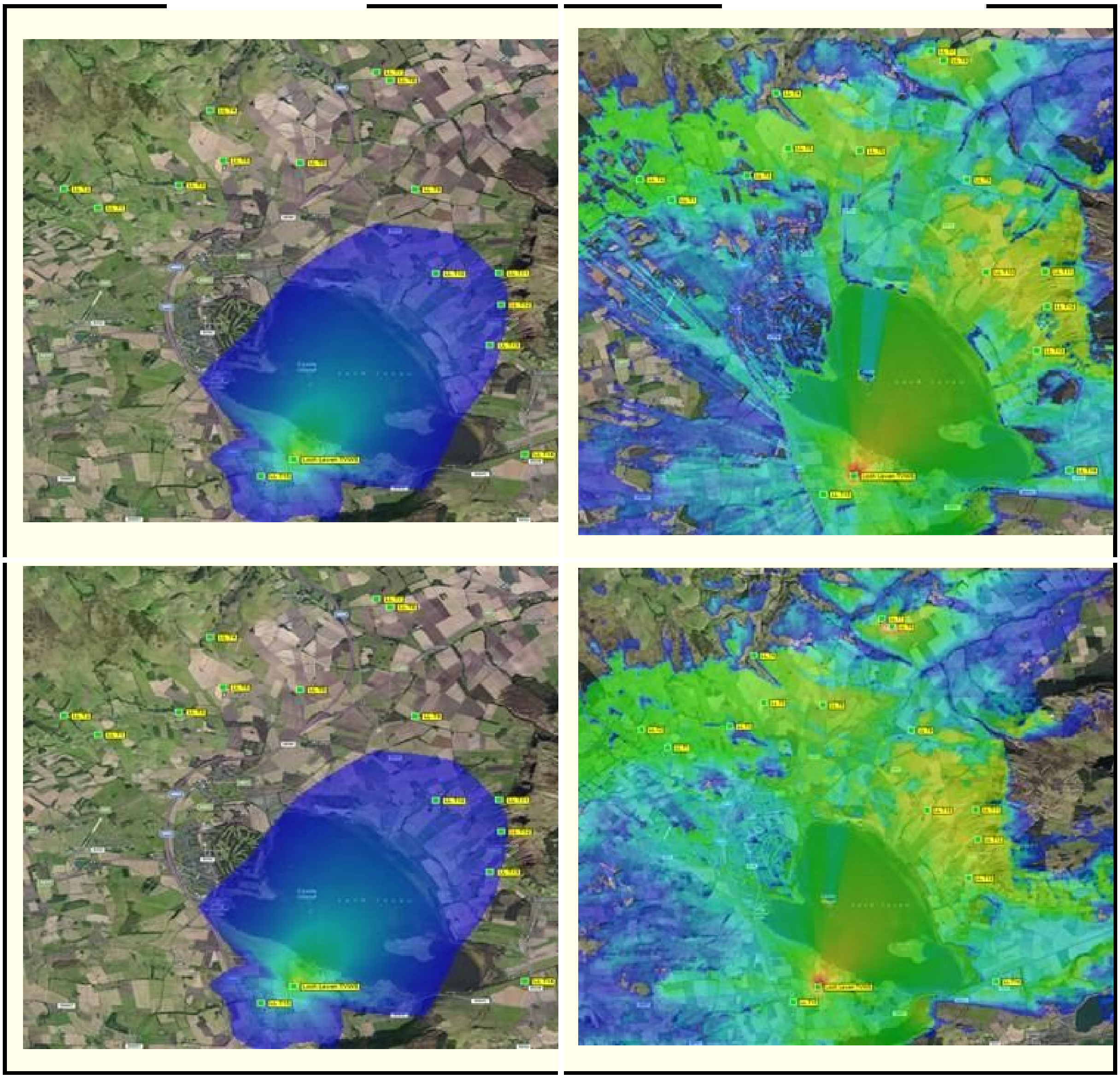
Base station WSD located in Classlochie, Perth and Kinross.

Base Details	LL TVWS Base
Lat	[redacted]
Lon	
Channel	59
Frequency	774 - 782
Power EIRP	30dBm
Height	1.5
Azimuth	30
Tilt	0
Receive Antenna	1.5 M
Receive Gain	12dBi

14.8.1. Perth & Kinross Propagation Models and Test Results

<u>14.8.1.1 30 Metre Propagation Coverage Maps</u>

30 Hata Tree | 30 Longley Tree



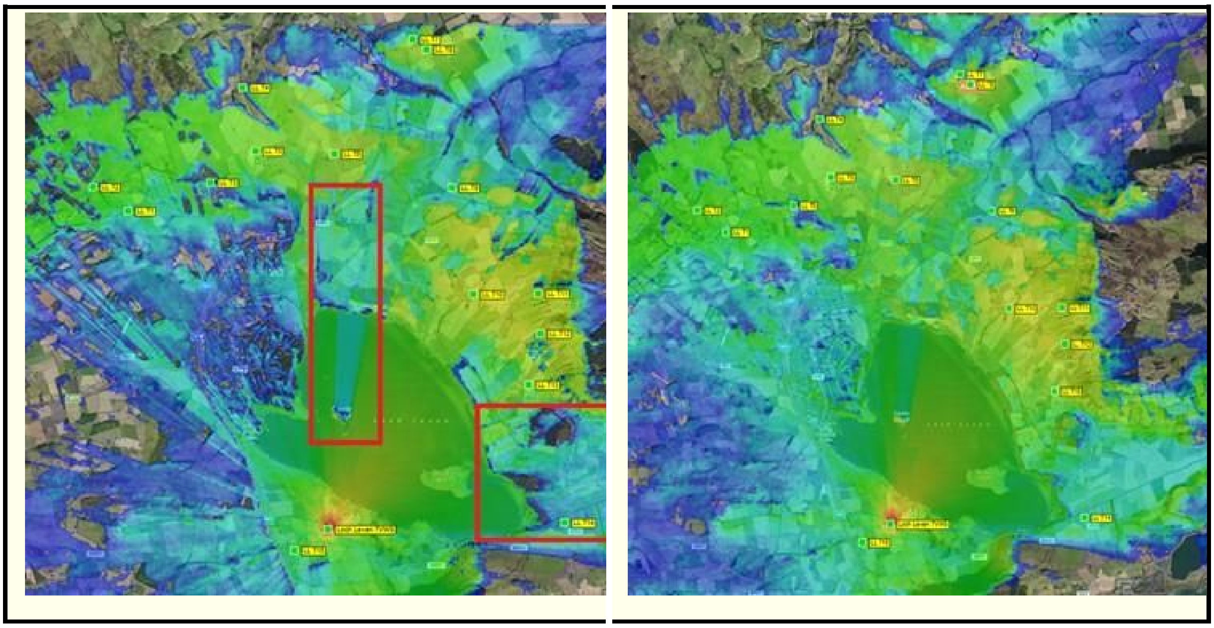
30 Hata | 30 Longley

14.8.1.2 30 Metre Test Results

30 Meter Test Data				Terrain and Clutter Model		Terrain Only		Test Results
Call Signs	Distance Meters	Long	Lat	30 Hata Tree	30 Longley Tree	30 Hata	30 Longley	Actual RSSI
LL T1	7482.58	[redacted]	[redacted]	No Signal	-81	-118	-80	No Signal
LL T2	8263.08	[redacted]	[redacted]	No Signal	-78	-119	-78	No Signal
LL T3	7285.99	[redacted]	[redacted]	No Signal	-112	-115	-103	No Signal
LL T4	8954.79	[redacted]	[redacted]	No Signal	-118	-117	-120	No Signal
LL T5	7666.45	[redacted]	[redacted]	No Signal	-74	-115	-74	-71
LL T6	7470.96	[redacted]	[redacted]	No Signal	-70	-110	-70	No Signal
LL T7	9893.68	[redacted]	[redacted]	No Signal	-97	-112	-104	-72
LL T8	9737.25	[redacted]	[redacted]	No Signal	-69	-111	-69	-86
LL T9	7240.7	[redacted]	[redacted]	No Signal	-95	-106	-88	-80
LL T10	5495.16	[redacted]	[redacted]	-119	-64	-101	-64	-67
LL T11	6268.28	[redacted]	[redacted]	-121	-64	-103	-64	-56
LL T12	5753.51	[redacted]	[redacted]	-121	-64	-103	-64	-67
LL T13	4920.82	[redacted]	[redacted]	-120	-71	-102	-71	-57
LL T14	4711.53	[redacted]	[redacted]	No Signal	-110	-110	-98	-84
LL T15	782.3	[redacted]	[redacted]	-112	-90	-94	-86	-75

Poor results with Hata. Better results from a terrain-based model.

Interestingly, the best results were from the 30 Longley data. I think this is because the trees in the environment are casting a “shadow” and the signal is propagating much better than the propagation model is predicting.

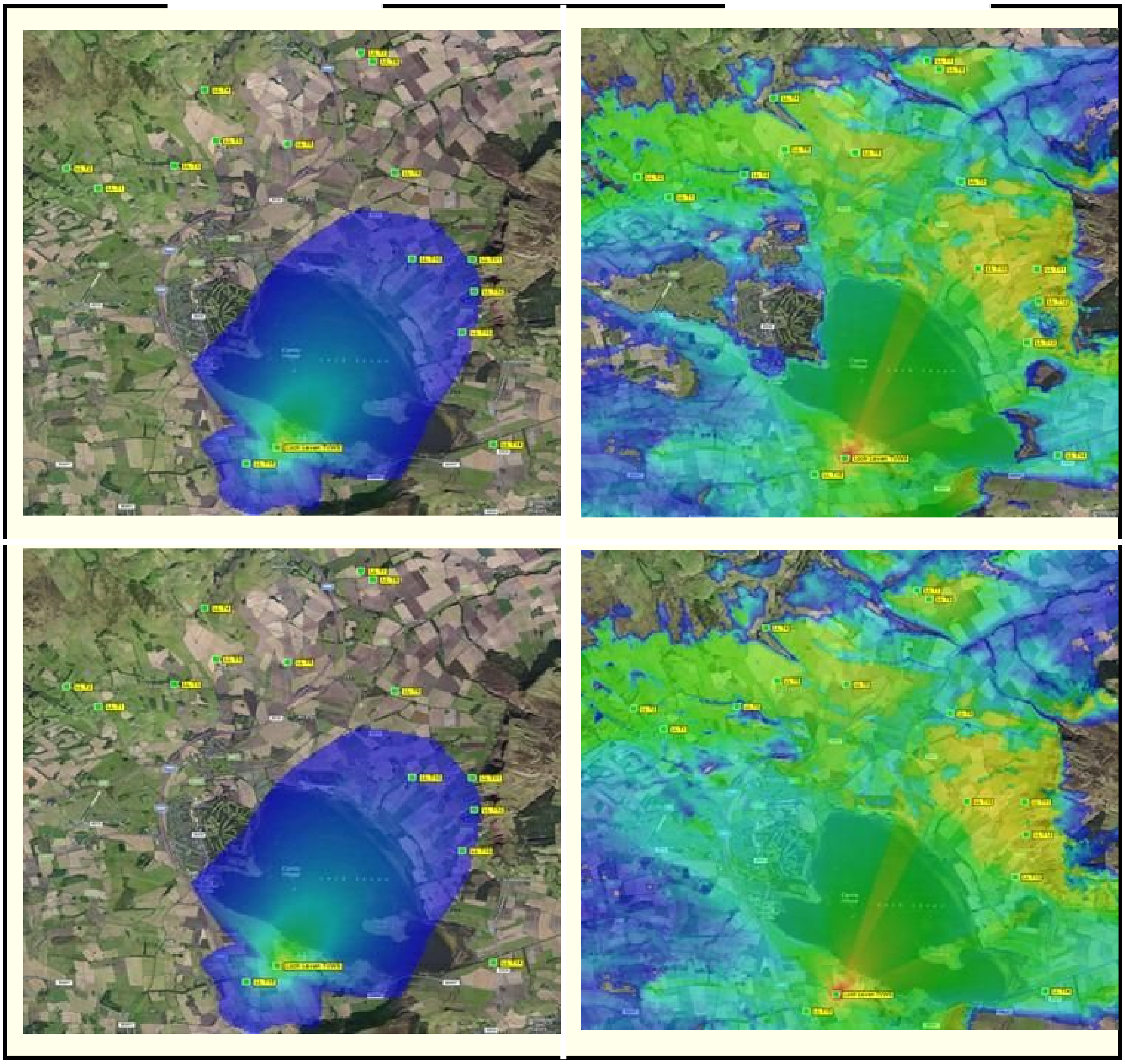


By enlarging, the most accurate results appeared to be 30 Longley with neither Hata model particularly close to matching test results.

14.8.1.3 50 Metre Propagation Coverage Maps

50 Hata Corine

50 Longley Corine



50 Hata

50 Longley

14.8.1.4 50 Metre Test Results

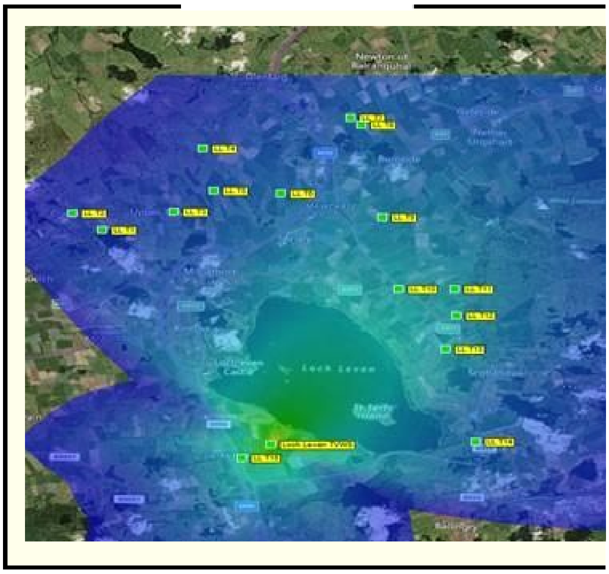
50 Meter Test Data				Terrain and Clutter Model		Terrain Only		Test Results
Call Signs	Distance Meters	Long	Lat	50 Hata Corine	50 Longley Corine	50 Hata	50 Longley	Actual RSSI
LL T1	7482.58	[redacted]		No Signal	-88	-118	-81	No Signal
LL T2	8263.08	[redacted]		No Signal	-78	-119	-78	No Signal
LL T3	7285.99	[redacted]		No Signal	-101	-115	-99	No Signal
LL T4	8954.79	[redacted]		No Signal	-74	-117	-115	No Signal
LL T5	7666.45	[redacted]		No Signal	-118	-115	-74	-71
LL T6	7470.96	[redacted]		No Signal	-71	-110	-71	No Signal
LL T7	9893.68	[redacted]		No Signal	-113	-112	-113	-72
LL T8	9737.25	[redacted]		No Signal	-70	-111	-70	-86
LL T9	7240.7	[redacted]		No Signal	-93	-106	-95	-80
LL T10	5495.16	[redacted]		-119	-65	-101	-65	-67
LL T11	6268.28	[redacted]		-121	-64	-103	-64	-56
LL T12	5753.51	[redacted]		-121	-64	-103	-64	-67
LL T13	4920.82	[redacted]		-120	-73	-102	-71	-57
LL T14	4711.53	[redacted]		No Signal	-107	-110	-91	-84
LL T15	782.3	[redacted]		-112	-89	-94	-92	-75

No resemblance to reality from either Hata model.

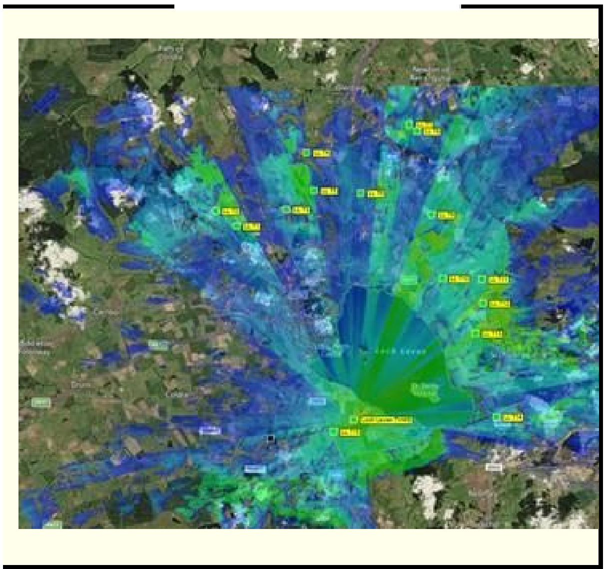
Almost identical performance from the 50 Longley Corine data and the 50 Longley data. The most accurate appears to be the terrain model which strengthens the argument that more work is needed on attenuation from trees. It is almost not worth having clutter and just adopting a terrain only model from this set of results.

14.8.1.5 2 Metre Propagation Coverage Maps

2M Hata



2M Longley



14.8.1.6 2 Metre Test Results

2 Meter Test Data				Terrain and Clutter Model		Test Results
Call Signs	Distance Meters	Long	Lat	2m Hata	2m Longley	Actual RSSI
LL T1	7482.58	[redacted]		-129	-106	No Signal
LL T2	8263.08			-131	-113	No Signal
LL T3	7285.99			-127	-133	No Signal
LL T4	8954.79			-129	-133	No Signal
LL T5	7666.45			-127	-127	-71
LL T6	7470.96			-122	-127	No Signal
LL T7	9893.68			-124	-123	-72
LL T8	9737.25			-117	-119	-86
LL T9	7240.7			-113	-108	-80
LL T10	5495.16			-115	-116	-67
LL T11	6268.28			-115	-111	-56
LL T12	5753.51			-114	-76	-67
LL T13	4920.82			-114	-82	-57
LL T14	4711.53			-122	-119	-84
LL T15	782.3			-106	-98	-75

The 2 metre data seems to increase attenuation exponentially for objects in the Fresnel path. For high frequency planning this is probably a good thing, but for low frequency it has a negative effect.

14.8.2. Perth and Kinross Summary

Recommended Model Comparison							
Call Signs	Distance Meters	Long	Lat	30 Longley	50 Longley	2m Longley	Actual RSSI
LL T1	7482.58	[redacted]		-80	-81	-106	No Signal
LL T2	8263.08			-78	-78	-113	No Signal
LL T3	7285.99			-103	-99	-133	No Signal
LL T4	8954.79			-120	-115	-133	No Signal
LL T5	7666.45			-74	-74	-127	-71
LL T6	7470.96			-70	-71	-127	No Signal
LL T7	9893.68			-104	-113	-123	-72
LL T8	9737.25			-69	-70	-119	-86
LL T9	7240.7			-88	-95	-108	-80
LL T10	5495.16			-64	-65	-116	-67
LL T11	6268.28			-64	-64	-111	-56
LL T12	5753.51			-64	-64	-76	-67
LL T13	4920.82			-71	-71	-82	-57
LL T14	4711.53			-98	-91	-119	-84
LL T15	782.3			-86	-92	-98	-75

The best propagation model for this environment is 50 Longley.

The attenuation caused by clutter is skewing test results and more work is needed to understand the attenuation characteristics.

Further investigation is worthwhile for locations LL T2 and LLT6.

There are question-marks over the 2M data results which will be investigated, especially for the Hata model. Certainly for low frequency this type of data does not look suitable for this type of planning.

14.9. Cheshire

Delamere Forrest

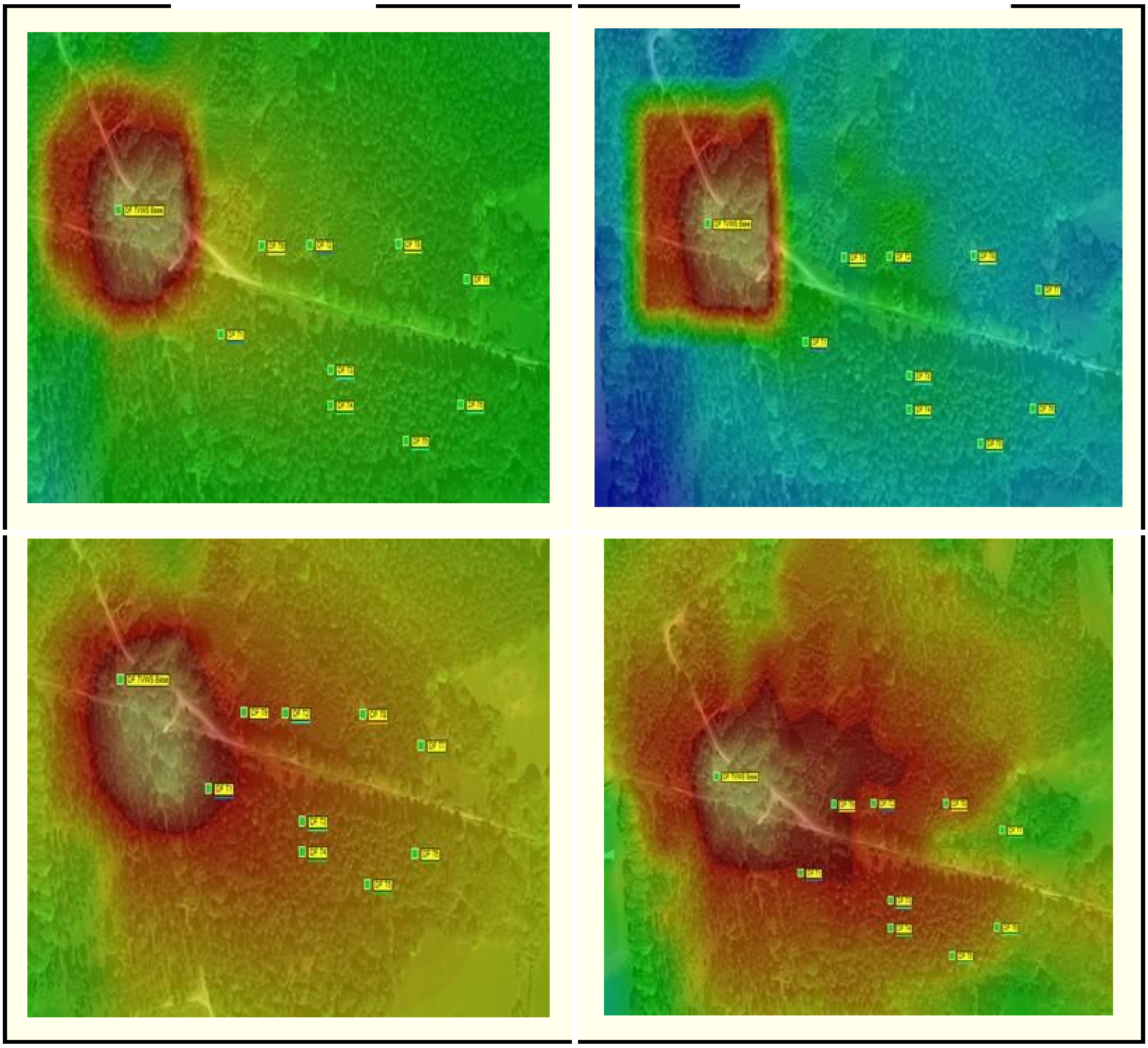
Base station WSD located in Delamere Forrest, Cheshire.

Base Details	LL TVWS Base
Lat	[redacted]
Lon	[redacted]
Channel	44
Frequency	654-662
Power EIRP	30dBm
Height	1.5
Azimuth	102
Tilt	0
Receive Antenna	1.5 M
Receive Gain	12dBi

14.9.1. Cheshire Propagation Models and Test Results

14.9.1.1 30 Metre Propagation Coverage Maps

30 Hata Tree 30 Longley Tree



14.9.1.2 30 Metre Test Results

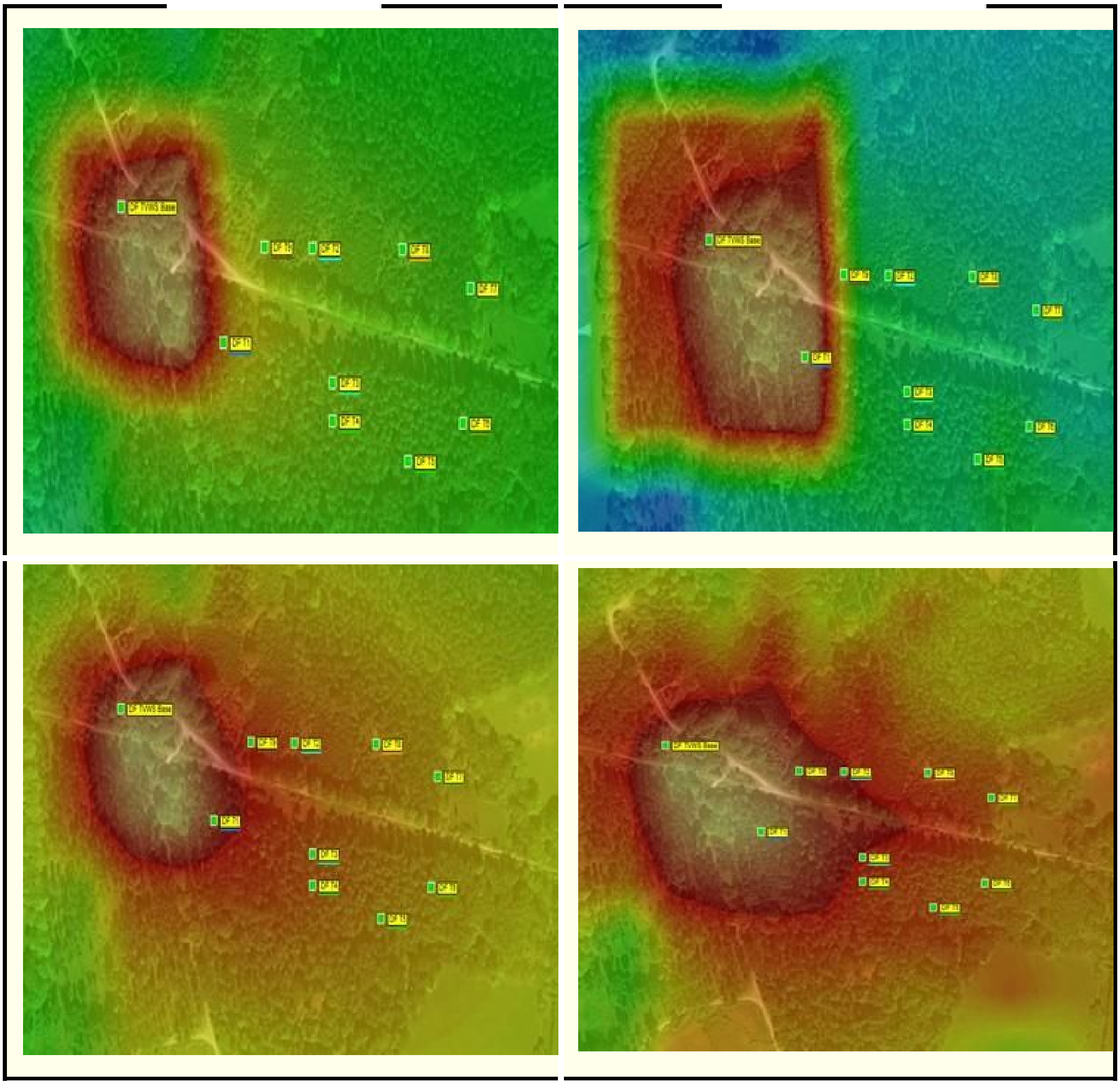
30 Meter Test Data				Terrain and Clutter Model		Terrain Only		Test Results
Call Signs	Distance Meters	Long	Lat	30 Hata Tree	30 Longley Tree	Hata 30	Longley 30	Actual RSSI
DF T1	127.28	[redacted]		-66	-83	-47	-43	-38
DF T2	182.48			-67	-83	-49	-45	-55
DF T3	241.87			-72	-91	-54	-45	-55
DF T4	241.87			-72	-91	-54	-45	-64
DF T5	308.87			-76	-96	-58	-53	-72
DF T6	351.14			-77	-97	-59	-54	-64
DF T7	335.41			-76	-102	-58	-68	-76
DF T8	271.66			-73	-97	-55	-47	-75
DF T9	152.97			-64	-90	-46	-38	-56

More obviously now we can see that the attenuation from trees is incorrect. The Hata 30 terrain only model is working in my opinion because it just so happens to match the test – free space path loss essentially the result.

DF T7 in particular is going through significant foliage, is obscured behind a small mound and is not directly in front of the antenna.

14.9.1.3 50 Metre Propagation Coverage Maps

50 Hata Corine 50 Longley Corine



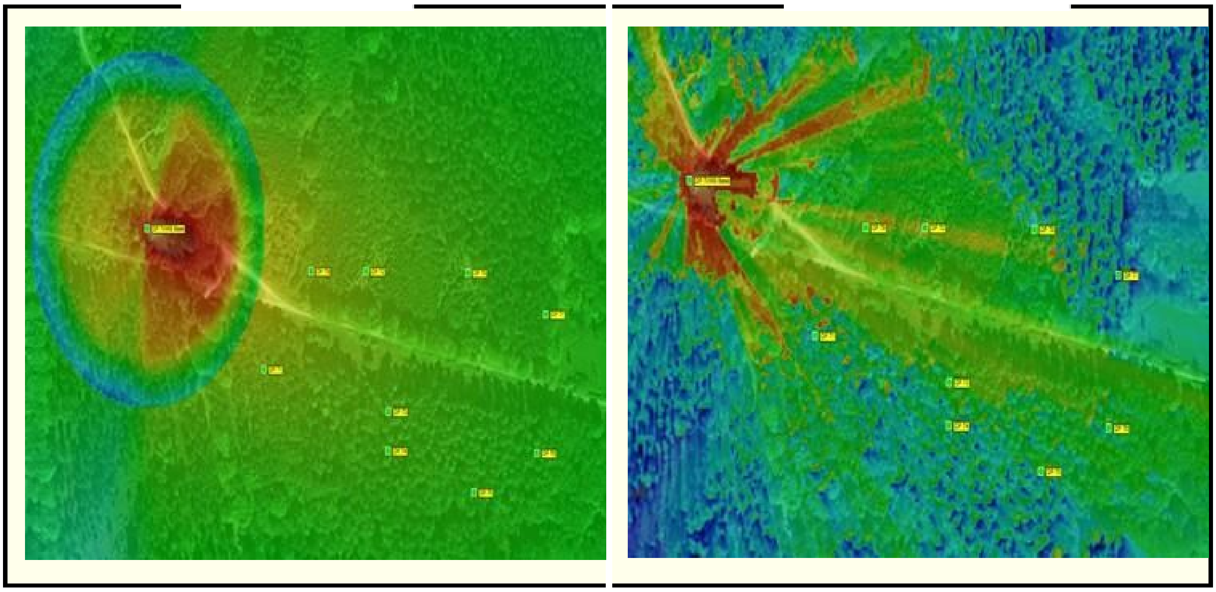
14.9.1.4 50 Metre Test Results

50 Meter Test Data				Terrain and Clutter Model		Terrain Only		Test Results
Call Signs	Distance Meters	Long	Lat	50 Corine Hata	Corine 50 Longley	Hata 50	Longley 50	Actual RSSI
DF T1	127.28	[redacted]	[redacted]	-66	-30	-47	-29	-38
DF T2	182.48	[redacted]	[redacted]	-67	-87	-49	-46	-55
DF T3	241.87	[redacted]	[redacted]	-72	-89	-54	-48	-55
DF T4	241.87	[redacted]	[redacted]	-72	-89	-54	-48	-64
DF T5	308.87	[redacted]	[redacted]	-76	-91	-58	-50	-72
DF T6	351.14	[redacted]	[redacted]	-77	-86	-59	-53	-64
DF T7	335.41	[redacted]	[redacted]	-76	-95	-58	-51	-76
DF T8	271.66	[redacted]	[redacted]	-73	-91	-55	-49	-75
DF T9	152.97	[redacted]	[redacted]	-64	-87	-46	-40	-56

While the Hata model works best in this test, I believe that this is again simply due to the free space path loss characteristics of the model with no clutter.

14.9.1.5 2 Metre Propagation Coverage Maps

2M Hata 2M Longley



14.9.1.6 2 Metre Test Results

2 Meter Test Data				Terrain and Clutter Model		Test Results
Call Signs	Distance Meters	Long	Lat	2m Hata	2m Longley	Actual RSSI
DF T1	127.28	[redacted]	[redacted]	-47	-81	-38
DF T2	182.48	[redacted]	[redacted]	-49	-48	-55
DF T3	241.87	[redacted]	[redacted]	-53	-73	-55
DF T4	241.87	[redacted]	[redacted]	-55	-82	-64
DF T5	308.87	[redacted]	[redacted]	-58	-80	-72
DF T6	351.14	[redacted]	[redacted]	-59	-78	-64
DF T7	335.41	[redacted]	[redacted]	-59	-111	-76
DF T8	271.66	[redacted]	[redacted]	-52	-75	-75
DF T9	152.97	[redacted]	[redacted]	-45	-64	-56

The 2 metre results lean towards 2 metre Hata again. Again for clarity I believe this is because there is no clutter data and the model is replicating free space path loss type calculations.

14.9.2. Cheshire Summary

Recommended Model Comparison							
Call Signs	Distance Meters	Long	Lat	Hata 30	Hata 50	2m Hata	Actual RSSI
DF T1	127.28	[redacted]	[redacted]	-47	-47	-47	-38
DF T2	182.48	[redacted]	[redacted]	-49	-49	-49	-55
DF T3	241.87	[redacted]	[redacted]	-54	-54	-53	-55
DF T4	241.87	[redacted]	[redacted]	-54	-54	-55	-64
DF T5	308.87	[redacted]	[redacted]	-58	-58	-58	-72
DF T6	351.14	[redacted]	[redacted]	-59	-59	-59	-64
DF T7	335.41	[redacted]	[redacted]	-58	-58	-59	-76
DF T8	271.66	[redacted]	[redacted]	-55	-55	-52	-75
DF T9	152.97	[redacted]	[redacted]	-46	-46	-45	-56

I think the test proves that attenuation characteristics from tree clutter in particular are far less aggressive than we have in our model. I do not think the tests prove that Hata with no clutter is a good model for anything based on previous test results.

For now I would disregard the propagation model simulation until more research is carried out.

15. Q1: Propagation Modelling Summary - Answer

The Hata model has produced exactly the same results for all clutter and terrain types except the 2M data which did not have clutter data as a layer. The clutter is in the surface model but calculated as part of the terrain which Hata Extended is not supposed to calculate.

The reason it has produced the same results for the 30 and 50 metre dataset is because of the conditions we have chosen to replicate. The model does not take into account terrain data and all clutter types are mapped to suburban and urban so we get the same result every single time.

The confusing part is why the 2 metre data is behaving differently and we will investigate this over the next few months. Consultation with ATDI should reveal the issue.

We need to do more work on understanding attenuation from trees because none of the models got close to a sensible set of outcomes. The Hata model predictions in Delamere were purely through the conditions of the test, going by what we have observed in Arran and Perthshire.

If more low frequency legislation is approved for Shared Spectrum then I recommend a terrain based model rather than a clutter only model. The data sources themselves are free and the computing processing overhead is very low indeed.

As computing processing is almost a commodity these days I recommend that be removed from any argument against terrain based models.

For low frequency planning there does not appear to be much point in increasing the terrain resolution past 50 metres.

If you are planning on deploying in similar areas as we have tested in Arran and Perth and Kinross then I recommend the Longley Rice model with Terrain 50 and no clutter.

For a worse case scenario add the clutter data and rerun the test.

16. Question 2: Has TVWS come of age?

To recap the question: Has TV White Space come of age? Can White Space technology be utilised now to deliver applications such as broadband and achieve modern performance standards?

Note - Broadway is working with Lancaster University to install monitoring devices to check that the TVWS links are achieving NGA standards. Following compliance issues and delays in deploying equipment this test is ongoing with the onus on Broadway now to complete the monitoring and installation work on behalf of Lancaster.

We have additional deployments planned over the next two months that are delayed due to project dependencies. In the case of all remaining links, permission to site equipment from 3rd parties is the only dependency outstanding.

Currently we have Point to Point links in Inverness, Isle of Arran and Perth and Kinross.

We have a Point to Multipoint link in Kintyre.

16.1. What are modern performance standards?

16.1.1. NGA – Next Generation Access

Here is a link to Ofcom's NGA assessment template.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/543596/NGA_Assessment_Template_v2.1_DRAFT_with_Marked_Changes__2_.docx

For the purposes of the initial test we will focus on the download element exceeding 30Mbps.

16.1.2. USO – Universal Service Obligation

For the USO, Government has defined decent broadband as a service that can provide a download speed of 10 Mbps.

16.1.3. General Approach

While there was initial comfort from the early testing, Broadway set out to answer the question starting with simple deployments rather than pushing the boundaries of the technology with the first part of the pilot. Following successful implementation and data from propagation testing we hoped to expand the scope of the pilot to more difficult deployments.

We decided that until more was understood about propagation and potential link performance, interpreting results would include a lot of wild assumptions and potentially lengthy troubleshooting.

There was a distinct risk that at the end of the pilot the question would remain completely unanswered if we added too many variables into the tests.

On the other hand, we did not want to make it too easy and wanted to capture real world issues as they presented themselves.

The two factors we took into account prior to deployment were distance and theoretical channel availability. In other words, what the WSD database said was available, not what was actually available when we arrived at sight.

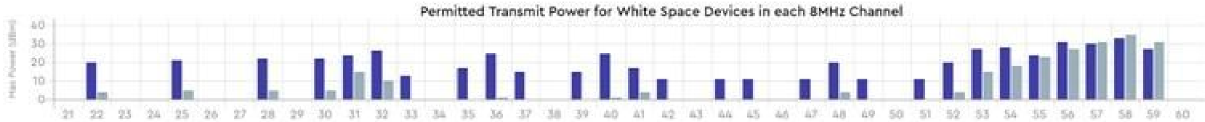
Please note that link profiles always profile from the Base Station to the client – left to right.

16.2. Isle of Arran – Point to Point

HuWoMobility Deployment to local farmer approximately 1.3KM NLOS.

(image removed)

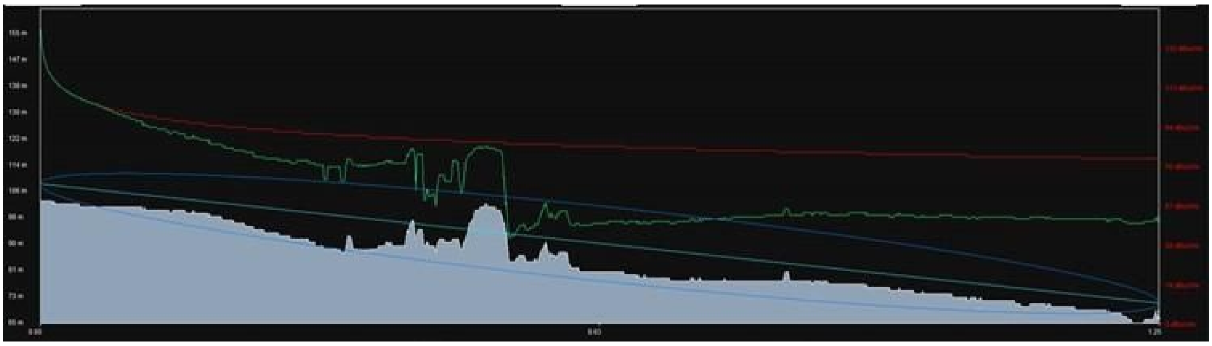
16.2.1. Channel Availability



There are a few higher powered, contiguous channels at the higher end of the range.

16.2.2. ATDI Link Profile

The link is approximately 1.3KM. It has dense trees impeding the middle of the link and is NLOS.



16.2.3. Site Images

Base Station antenna mounted on farm building approximately 4 metres in height.

Base Station

Base Station LOS

Client

Client LoS

16.2.4. ink Performance

Base	3 Meters			Upload from Client		
Frequency	Channel (s)	EIRP	Base RSSI	RX Modulation	Base Noise	Base SNR
8Mhz	58	31dBm	-56	MCS 14	-88	32
16Mhz	57, 58	30dBm	-58	MCS 14	-87	29
24Mhz	56, 57, 58	30dBm	No Link	-	-	-

Client	5 Meters			Download from Base			NGA Download Test
Frequency	Channel (s)	EIRP	Client RSSI	TX Modulation	Client Noise	Client SNR	iPerf Download Mbps
8Mhz	58	30dBm	-56	MCS 15	-92	-36	27.4
16Mhz	57, 58	30dBm	-64	MCS 15	-95	-31	32.3
24Mhz	56, 57, 58	30dBm	No Link	-	-	-	-

The 8MHz channel offered excellent economy achieving 27.4mbps TCP on iPerf.

Whilst performance was not bad and modulation was very high showing that MIMO was working, we were expecting much better performance on the 16MHz channel especially at the SNR and MCS level.

Initially we considered that there was a noise issue. We monitored the link to see if the noise floor deteriorated, but it remained steady and consistent.

We replaced the antenna and feeder cable and replaced the radios at both ends.

We were not able to establish a link on the 24MHz channel. We tried the radios slightly higher than pictured but were not able to establish a connection of any sort.

We have not been able to replicate this phenomenon anywhere else during testing without seeing impact to RSSI or noise.

16.2.4.1 iPerf 8MHz

```
:\iPerf>iperf -c 192.168.213.200 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.213.200, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  6] local 192.168.212.16 port 57313 connected with 192.168.213.200 port 5001
[  4] local 192.168.212.16 port 57311 connected with 192.168.213.200 port 5001
[  5] local 192.168.212.16 port 57312 connected with 192.168.213.200 port 5001
[  3] local 192.168.212.16 port 57310 connected with 192.168.213.200 port 5001
[ ID] Interval       Transfer     Bandwidth
[  6]  0.0-20.0 sec  17.9 MBytes  7.49 Mbits/sec
[  5]  0.0-20.0 sec  18.2 MBytes  7.64 Mbits/sec
[  3]  0.0-20.0 sec  15.0 MBytes  6.28 Mbits/sec
[  4]  0.0-20.1 sec  14.6 MBytes  6.10 Mbits/sec
[SUM]  0.0-20.1 sec  65.8 MBytes  27.4 Mbits/sec
```

16.2.4.2 iPerf 16MHz

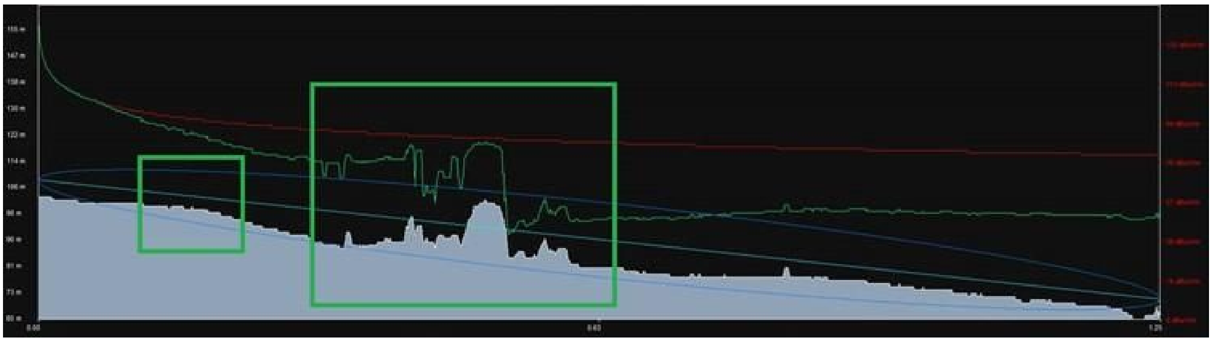
```
C:\iPerf>iperf -c 192.168.213.200 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.213.200, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  6] local 192.168.212.16 port 57149 connected with 192.168.213.200 port 5001
[  4] local 192.168.212.16 port 57147 connected with 192.168.213.200 port 5001
[  3] local 192.168.212.16 port 57146 connected with 192.168.213.200 port 5001
[  5] local 192.168.212.16 port 57148 connected with 192.168.213.200 port 5001
[ ID] Interval       Transfer     Bandwidth
[  5]  0.0-20.0 sec  19.8 MBytes  8.28 Mbits/sec
[  3]  0.0-20.0 sec  18.2 MBytes  7.64 Mbits/sec
[  4]  0.0-20.1 sec  18.4 MBytes  7.68 Mbits/sec
[  6]  0.0-20.2 sec  21.4 MBytes  8.88 Mbits/sec
[SUM]  0.0-20.2 sec  77.8 MBytes  32.3 Mbits/sec
```

16.2.5. Summary

The link achieved NGA download speeds on a 16MHz channel but the additional bandwidth compared to the 8MHz channel did not have the expected improvements.

This could be because of attenuation from the trees in the middle of the path profile but I would expect to see less RSSI and less MCS if that was the primary factor. Further investigation is required over the coming months.

For a USO option the technology excels offering over three times the available bandwidth required.

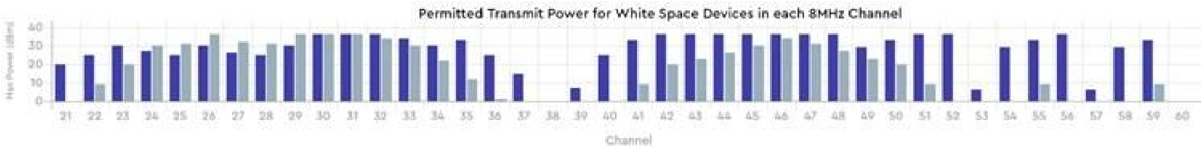


16.3. Kintyre Peninsula Deployment – Point to Multipoint Deployment

HuWoMobility Deployment to two properties.

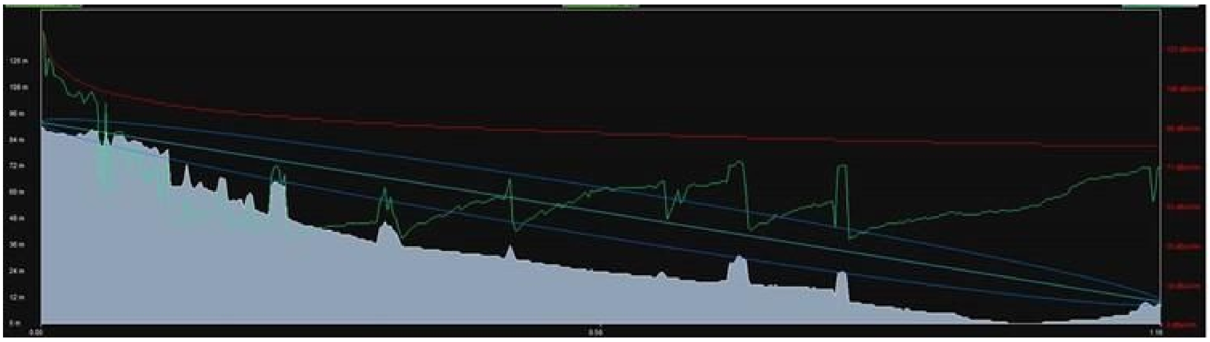
(image removed)

16.3.1. Channel Availability



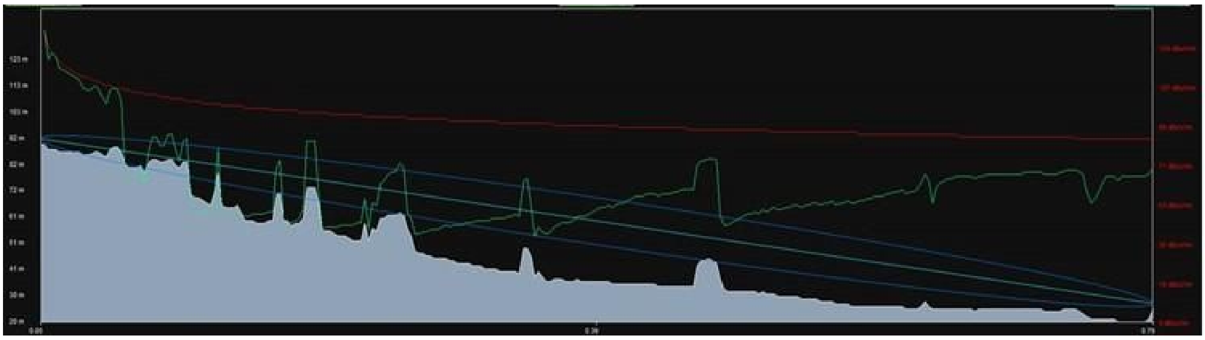
There are quite a few channels available to experiment with. Channels 30, 31, 32 and 33 look exceptionally good.

16.3.2. ATDI Link Profile Property 1



The DSM data looks distinctly less dense than it seems in real life. The signal appears to be going through the tops of the trees. The trees do not have any leaves on so it will be interesting to see performance during the summer.

16.3.3. ATDI Link Profile to Property 2



Similar observation to Property 1. The trees certainly seem more dense and larger than the DSM suggests.

16.3.4. Site Images

Base Station antenna mounted on farm building approximately 4 metres in height.

Base Station	Base Station LOS Both End Points
	
	

Client Station Property 2	Client LOS Property 2
	

16.3.5. Link Performance Property 1

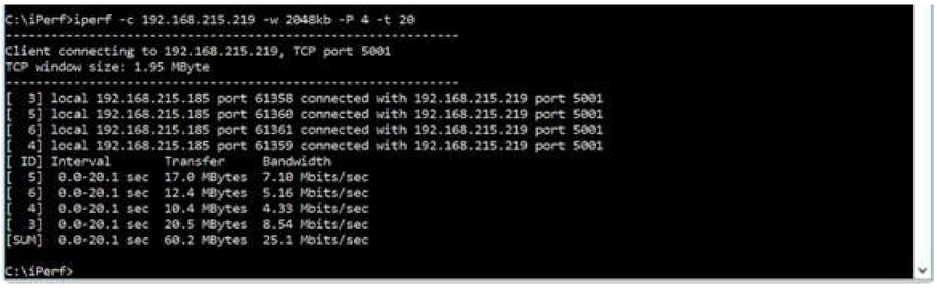
Base	5 Meters			Upload from Client		
Frequency	Channel (s)	EIRP	Base RSSI	RX Modulation	Base Noise	Base SNR
8Mhz	30	32dBm	-52	MCS 11	-71	21
16Mhz	31,32	32dBm	-52	MCS 11	-72	20
24Mhz	30,31,32	32dBm	-54	MCS 11	-73	19

Client	5 Meters			Download from Base			NGA Download Test
Frequency	Channel (s)	EIRP	Client RSSI	TX Modulation	Client Noise	Client SNR	iPerf Download Mbps
8Mhz	30	32dBm	-52	MCS 15	-90	39	25.1
16Mhz	31,32	32dBm	-53	MCS 15	-89	35	39.1
24Mhz	30,31,32	32dBm	-53	MCS 15	-90	35	45.9

Unlike the Isle of Arran, you can clearly see marked improvements in increased channel size. NGA download speeds easily achieved at 16 and 24MHz via iPerf with USO achieved easily.

As with the Isle of Arran, the base station is at the higher point in the network which has contributed to the noise floor drastically increasing, impacting achievable modulation on the upstream.

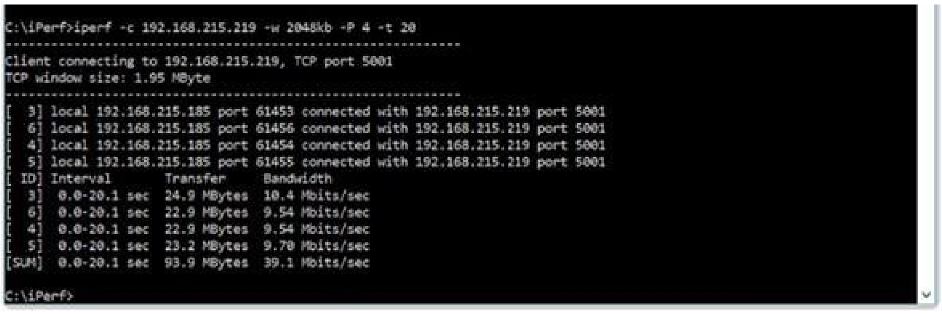
16.3.5.1 iPerf 8MHz



```
C:\iPerf>iperf -c 192.168.215.219 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.215.219, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  3] local 192.168.215.185 port 61358 connected with 192.168.215.219 port 5001
[  5] local 192.168.215.185 port 61360 connected with 192.168.215.219 port 5001
[  6] local 192.168.215.185 port 61361 connected with 192.168.215.219 port 5001
[  4] local 192.168.215.185 port 61359 connected with 192.168.215.219 port 5001
[ ID] Interval       Transfer     Bandwidth
[  5]  0.0-20.1 sec  17.0 MBytes  7.10 Mbits/sec
[  6]  0.0-20.1 sec  12.4 MBytes  5.16 Mbits/sec
[  4]  0.0-20.1 sec  10.4 MBytes  4.33 Mbits/sec
[  3]  0.0-20.1 sec  20.5 MBytes  8.54 Mbits/sec
[SUM]  0.0-20.1 sec  60.2 MBytes  25.1 Mbits/sec

C:\iPerf>
```

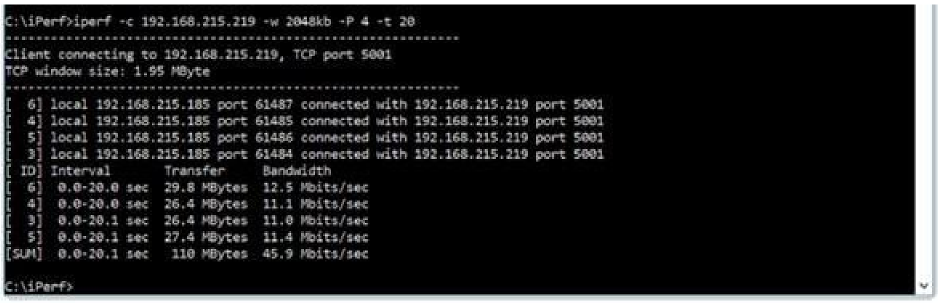
16.3.5.2 iPerf 16MHz



```
C:\iPerf>iperf -c 192.168.215.219 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.215.219, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  3] local 192.168.215.185 port 61453 connected with 192.168.215.219 port 5001
[  6] local 192.168.215.185 port 61456 connected with 192.168.215.219 port 5001
[  4] local 192.168.215.185 port 61454 connected with 192.168.215.219 port 5001
[  5] local 192.168.215.185 port 61455 connected with 192.168.215.219 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-20.1 sec  24.9 MBytes  10.4 Mbits/sec
[  6]  0.0-20.1 sec  22.9 MBytes  9.54 Mbits/sec
[  4]  0.0-20.1 sec  22.9 MBytes  9.54 Mbits/sec
[  5]  0.0-20.1 sec  23.2 MBytes  9.70 Mbits/sec
[SUM]  0.0-20.1 sec  93.9 MBytes  39.1 Mbits/sec

C:\iPerf>
```

16.3.5.3 iPerf 24MHz



```
C:\iPerf>iperf -c 192.168.215.219 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.215.219, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  6] local 192.168.215.185 port 61487 connected with 192.168.215.219 port 5001
[  4] local 192.168.215.185 port 61485 connected with 192.168.215.219 port 5001
[  5] local 192.168.215.185 port 61486 connected with 192.168.215.219 port 5001
[  3] local 192.168.215.185 port 61484 connected with 192.168.215.219 port 5001
[ ID] Interval       Transfer     Bandwidth
[  6]  0.0-20.0 sec  29.8 MBytes  12.5 Mbits/sec
[  4]  0.0-20.0 sec  26.4 MBytes  11.1 Mbits/sec
[  3]  0.0-20.1 sec  26.4 MBytes  11.0 Mbits/sec
[  5]  0.0-20.1 sec  27.4 MBytes  11.4 Mbits/sec
[SUM]  0.0-20.1 sec   110 MBytes  45.9 Mbits/sec

C:\iPerf>
```

16.3.6. Link Performance Property 2

Base	5 Meters			Upload from Client		
Frequency	Channel (s)	EIRP	Base RSSI	RX Modulation	Base Noise	Base SNR
8Mhz	31	32dBm	-49	MCS 12	-71	21
16Mhz	31, 32	32dBm	-54	MCS 11	-72	18
24Mhz	31, 32, 33	32dBm	-55	MCS 11	-73	18

Client	5 Meters			Download from Base			NGA Download Test
Frequency	Channel (s)	EIRP	Client RSSI	TX Modulation	Client Noise	Client SNR	iPerf Download Mbps
8Mhz	31	32dBm	-53	MCS 15	-90	37	29.7
16Mhz	31, 32	32dBm	-56	MCS 15	-90	34	38.2
24Mhz	31, 32, 33	32dBm	-54	MCS 15	-90	35	53.2

Almost parity with property 1. The link is stable and producing good speeds, nearly achieving NGA download speeds on an 8MHz channel and comfortably exceeding the USO. The link is shorter than property 1, which might explain the improvement.

16.3.6.1 iPerf 8MHz

```
C:\iPerf>iperf -c 192.168.215.219 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.215.219, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  5] local 192.168.215.185 port 60849 connected with 192.168.215.219 port 5001
[  3] local 192.168.215.185 port 60847 connected with 192.168.215.219 port 5001
[  4] local 192.168.215.185 port 60848 connected with 192.168.215.219 port 5001
[  6] local 192.168.215.185 port 60850 connected with 192.168.215.219 port 5001
[ ID] Interval       Transfer     Bandwidth
[  4]  0.0-20.0 sec  15.5 MBytes  6.49 Mbits/sec
[  5]  0.0-20.1 sec  15.5 MBytes  6.48 Mbits/sec
[  6]  0.0-20.4 sec  17.0 MBytes  6.99 Mbits/sec
[  3]  0.0-20.4 sec  24.4 MBytes  10.0 Mbits/sec
[SUM]  0.0-20.4 sec  72.4 MBytes  29.7 Mbits/sec

C:\iPerf>
```

16.3.6.2 iPerf 16MHz

```
C:\iPerf>iperf -c 192.168.215.219 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.215.219, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  6] local 192.168.215.185 port 60305 connected with 192.168.215.219 port 5001
[  5] local 192.168.215.185 port 60304 connected with 192.168.215.219 port 5001
[  3] local 192.168.215.185 port 60302 connected with 192.168.215.219 port 5001
[  4] local 192.168.215.185 port 60303 connected with 192.168.215.219 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-20.1 sec  22.5 MBytes  9.40 Mbits/sec
[  4]  0.0-20.1 sec  21.9 MBytes  9.14 Mbits/sec
[  6]  0.0-20.1 sec  22.0 MBytes  9.19 Mbits/sec
[  5]  0.0-20.1 sec  25.1 MBytes  10.5 Mbits/sec
[SUM]  0.0-20.1 sec  91.5 MBytes  38.2 Mbits/sec

C:\iPerf>_
```

16.3.6.3 iPerf 24MHz

```
C:\iPerf>iperf -c 192.168.215.219 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.215.219, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  3] local 192.168.215.185 port 60783 connected with 192.168.215.219 port 5001
[  4] local 192.168.215.185 port 60784 connected with 192.168.215.219 port 5001
[  6] local 192.168.215.185 port 60786 connected with 192.168.215.219 port 5001
[  5] local 192.168.215.185 port 60785 connected with 192.168.215.219 port 5001
[ ID] Interval       Transfer     Bandwidth
[  6]  0.0-20.0 sec  30.8 MBytes  12.9 Mbits/sec
[  5]  0.0-20.0 sec  32.0 MBytes  13.4 Mbits/sec
[  3]  0.0-20.1 sec  32.8 MBytes  13.7 Mbits/sec
[  4]  0.0-20.1 sec  31.9 MBytes  13.3 Mbits/sec
[SUM]  0.0-20.1 sec   127 MBytes  53.2 Mbits/sec

C:\iPerf>
C:\iPerf>
```

Command Prompt

16.3.7. Summary

Sometimes in a point to multipoint configuration you may observe decreased modulation for clients if one link is utilising more of the TDD air time, but the radio maintained steady modulation for both clients. We did not observe any demodulation during testing.

One observation is that the SNR improved on a 24MHz channel over a 16MHz channel. If there is channel availability and you are not worried about preserving bandwidth for coexistence it might be worth trying a larger channel if the installer is struggling with noise on an 8 or 16MHz channel.

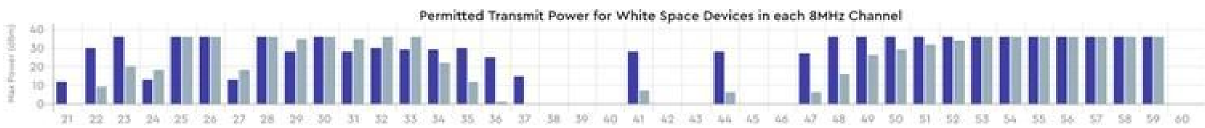
Both links achieved USO and NGA download speeds quite easily during testing.

16.4. Inverness Deployment – Point to Point Deployment

HuWoMobility Deployment to hotel near Loch Ness.

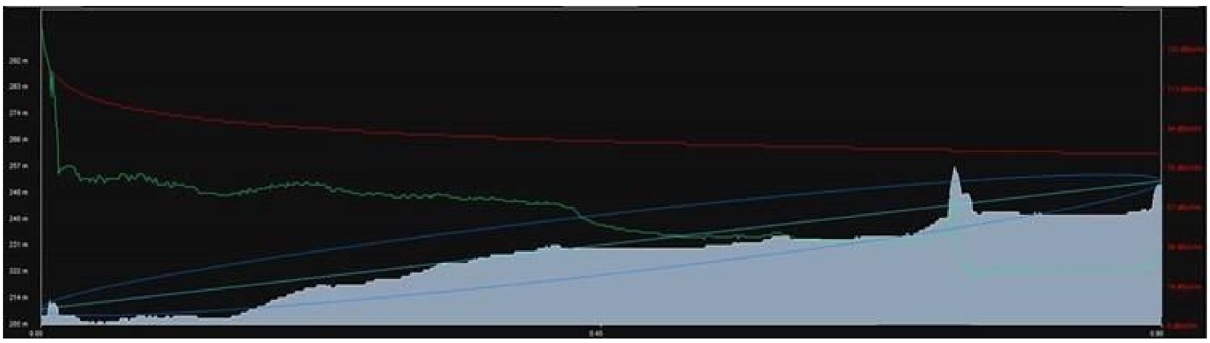
(image removed)

16.4.1. Channel Availability



The Arqiva DTT clearance is in advanced stages in Inverness-shire and the top end of the range is almost completely clear other than channel 60. Channels 25 and 26 are also good quality contiguous channels so far as power is concerned.

16.4.2. ATDI Link Profile



The link is clearly NLOS with terrain and tree clutter masking the client.

16.4.3. Site Images

Base Station antenna mounted on silo approximately 5 metres in height.

Base Station

Base Station LOS

Client Station Installation

Client LOS

16.4.4. Link Performance

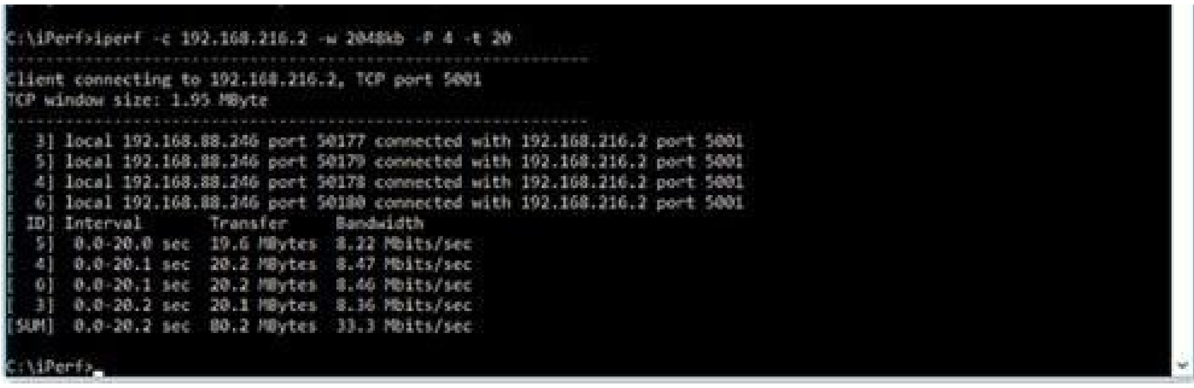
Base Frequency	5 Meters Channel (s)	EIRP	Base RSSI	Upload from Client RX Modulation	Base Noise	Base SNR
8Mhz	58	30dBi	-46	MCS 15	-95	49
16Mhz	57,58	30dBi	-49	MCS 15	-93	44
24Mhz	56,57,58	30dBi	-49	MCS 15	-92	43

Client Frequency	5 Meters Channel (s)	EIRP	Client RSSI	Download from Base TX Modulation	Client Noise	Client SNR	NGA Download Test iPerf Download Mbps
8Mhz	58	30dBi	-49	MCS 15	-95	46	33.3
16Mhz	57,58	30dBi	-52	MCS 15	-95	43	58
24Mhz	56,57,58	30dBi	-53	MCS 15	-94	41	70

Predictably the link performance is exceptional due to the SNR. There is still budget in the power to increase the link distance or add additional clutter.

The MIMO performance increase does not appear to be linear as the channels increase in bandwidth, but at 24Mhz to achieve 70Mbps is very impressive.

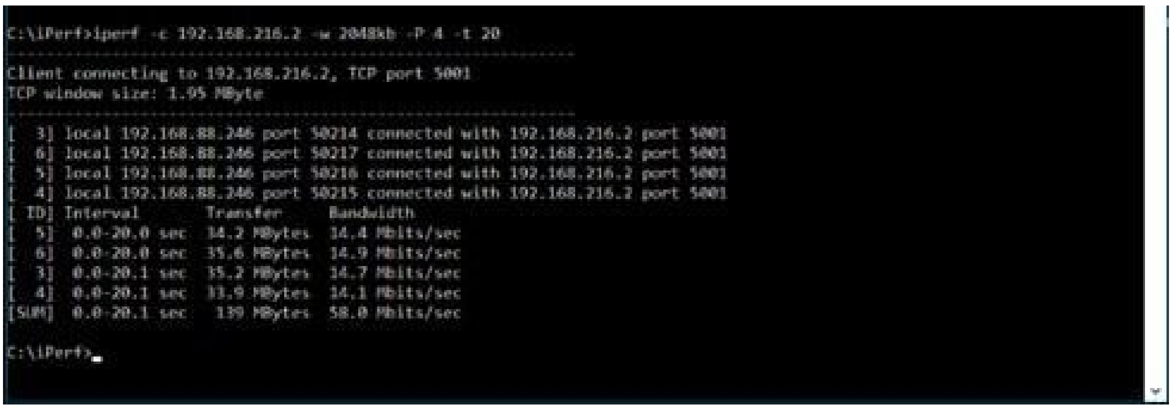
16.4.4.1 iPerf 8MHz



```
C:\iPerf>iperf -c 192.168.216.2 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.216.2, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  3] local 192.168.88.246 port 50177 connected with 192.168.216.2 port 5001
[  5] local 192.168.88.246 port 50179 connected with 192.168.216.2 port 5001
[  4] local 192.168.88.246 port 50178 connected with 192.168.216.2 port 5001
[  6] local 192.168.88.246 port 50180 connected with 192.168.216.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[  5]  0.0-20.0 sec  19.6 MBytes  8.22 Mbits/sec
[  4]  0.0-20.1 sec  20.2 MBytes  8.47 Mbits/sec
[  6]  0.0-20.1 sec  20.2 MBytes  8.46 Mbits/sec
[  3]  0.0-20.2 sec  20.1 MBytes  8.36 Mbits/sec
[SUM]  0.0-20.2 sec  80.2 MBytes  33.3 Mbits/sec

C:\iPerf>_
```

16.4.4.2 iPerf 16MHz



```
C:\iPerf>iperf -c 192.168.216.2 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.216.2, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  3] local 192.168.88.246 port 50214 connected with 192.168.216.2 port 5001
[  6] local 192.168.88.246 port 50217 connected with 192.168.216.2 port 5001
[  5] local 192.168.88.246 port 50216 connected with 192.168.216.2 port 5001
[  4] local 192.168.88.246 port 50215 connected with 192.168.216.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[  5]  0.0-20.0 sec  34.2 MBytes  14.4 Mbits/sec
[  6]  0.0-20.0 sec  35.6 MBytes  14.9 Mbits/sec
[  3]  0.0-20.1 sec  35.2 MBytes  14.7 Mbits/sec
[  4]  0.0-20.1 sec  33.9 MBytes  14.1 Mbits/sec
[SUM]  0.0-20.1 sec   139 MBytes  58.0 Mbits/sec

C:\iPerf>_
```

16.4.4.3 iPerf 24MHz

```
C:\iPerf>iperf -c 192.168.216.2 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.216.2, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  4] local 192.168.88.246 port 50161 connected with 192.168.216.2 port 5001
[  3] local 192.168.88.246 port 50160 connected with 192.168.216.2 port 5001
[  5] local 192.168.88.246 port 50162 connected with 192.168.216.2 port 5001
[  6] local 192.168.88.246 port 50163 connected with 192.168.216.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[  5]  0.0-20.0 sec  42.4 MBytes  17.8 Mbits/sec
[  4]  0.0-20.0 sec  40.2 MBytes  16.9 Mbits/sec
[  3]  0.0-20.1 sec  41.5 MBytes  17.4 Mbits/sec
[  6]  0.0-20.1 sec  43.4 MBytes  18.1 Mbits/sec
[SUM]  0.0-20.1 sec   168 MBytes  70.0 Mbits/sec

C:\iPerf>
```

16.4.5. Summary

NGA download speeds were achieved across 8, 16 and 24MHz channels comfortably with 7 times the USO capacity at 24MHz.

16.5. Perthshire 6H Installation

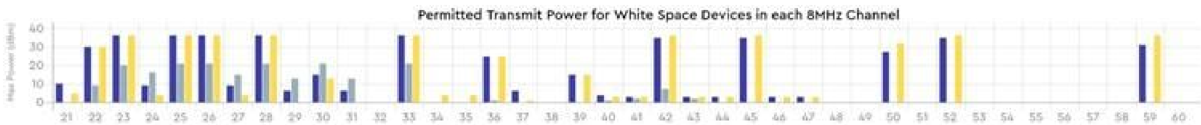
Local Business Person - Remote CCTV and General Internet Access

(image removed)

Initially we planned to install a HuWoMobility radio to test the range of the equipment but during installation did not feel the available mounting location would support the larger antenna. In addition, because of a planning miscalculation there was no uplink channel availability for the HuWo radio.

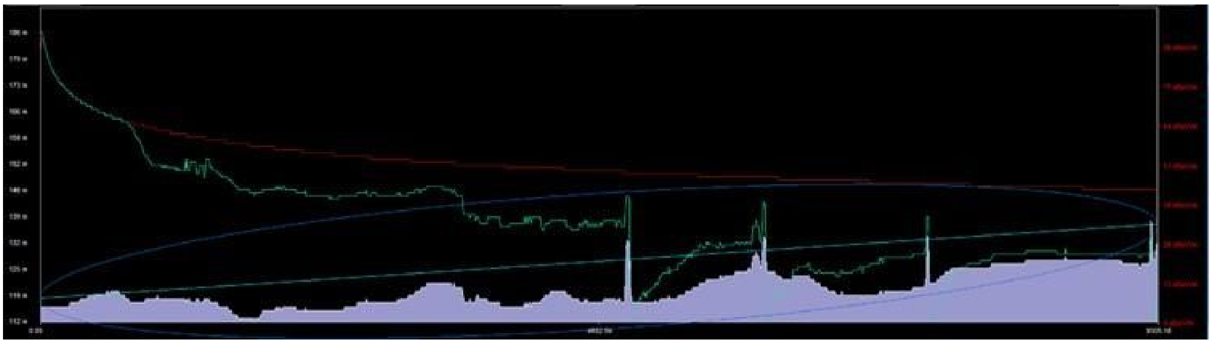
As we had a willing participant we decided to try the 6H equipment which has a much smaller, single Yagi antenna. Due to the fact the 6H radio has GPS in the client radio there are additional power benefits for the client.

16.5.1. Channel Availability



There are no 24MHz channels available in the area to test but there are 2 16 MHz channels in 22/23 and 25/26.

16.5.2. ATDI Link Profile



There is a building and 4 or 5 sets of trees in the profile path. The link distance is around 1km total distance.

16.5.3. Link Performance

Base Frequency	5 Meters Channel (s)	EIRP	Base RSSI	Upload from Client RX Modulation	Base Noise	Base SNR
8Mhz	33	30dBi	-82	MCS 5	-100	18
16Mhz	22, 23	30dBi	No Link	No Link	No Link	No Link
16Mhz	25, 26	30dBi	No Link	No Link	No Link	No Link
16Mhz	26, 27	30dBi	No Link	No Link	No Link	No Link

Client Frequency	5 Meters Channel (s)	EIRP	Client RSSI	Download from Base TX Modulation	Client Noise	Client SNR	NGA Download Test iPerf Download Mbps
8Mhz	33	30dBi	-83	MCS 7	-100	17	14
16Mhz	22, 23	30dBi	No Link	No Link	No Link	No Link	No Link
16Mhz	25, 26	30dBi	No Link	No Link	No Link	No Link	No Link
16Mhz	26, 27	30dBi	No Link	No Link	No Link	No Link	No Link

We believe the reason we cannot establish a connection on the 16MHz channels is due to the noise floor at the client end. The radio is receiving at -83 which is quite a low signal but achieving excellent modulation in part due to the very clean channel 33. The channel bandwidth is being utilised very efficiently and performance is excellent. In lab tests we can achieve circa 15Mbps TCP per 8MHz channel on a non-MIMO device.

16.5.3.1 iPerf 8MHz

```
C:\iPerf>iperf -c 192.168.178.132 -w 2048kb -P 4 -t 20
------------------------------------------------------------
Client connecting to 192.168.178.132, TCP port 5001
TCP window size: 1.95 MByte
------------------------------------------------------------
[  6] local 192.168.178.104 port 52870 connected with 192.168.178.132 port 5001
[  3] local 192.168.178.104 port 52867 connected with 192.168.178.132 port 5001
[  5] local 192.168.178.104 port 52869 connected with 192.168.178.132 port 5001
[  4] local 192.168.178.104 port 52868 connected with 192.168.178.132 port 5001
[ ID] Interval       Transfer     Bandwidth
[  4]  0.0-20.1 sec  5.12 MBytes  2.14 Mbits/sec
[  6]  0.0-20.2 sec  17.4 MBytes  7.22 Mbits/sec
[  5]  0.0-20.3 sec  5.88 MBytes  2.42 Mbits/sec
[  3]  0.0-20.4 sec  5.75 MBytes  2.36 Mbits/sec
[SUM]  0.0-20.4 sec  34.1 MBytes  14.0 Mbits/sec

C:\iPerf>
```

16.5.4. Summary

Finding a contiguous and available clean channel in Kinross is extremely challenging. We have managed a 16MHz channel but the SNR was down at 9dBi. When we returned to the radio the channel had disconnected.

When we tried to replicate the link it would not work. We have noticed that sometimes the radio connects and sometimes it does not. Unfortunately, we have never managed to be able to run tests when it does connect.

Because we only got the link working on channel 33 with a lot of disruption to the end user and as it is now performing well (the first time the pilot customer had ever watched iPlayer without buffering!), we decided to stop trying to improve the link with incremental changes.

Instead we will introduce a filter from the manufacturer to see if that improves noise resistance and continue to report over the coming months.

17. Q2: Has TV White Space Come of Age - Answer

Has TV White Space come of age? Can White Space technology be utilised now to deliver applications such as broadband and achieve modern performance standards?

I believe that in certain deployment scenarios TV White Space can achieve NGA download speeds and in most circumstances tested to date can achieve USO. However, although TV White Space is a technology that can be deployed en masse in every single area due to the noise and channel availability constraints, we are reassured by the efforts of manufacturers such as 6Harmonics, HuWoMobility and Radwin – partnering with Microsoft as part of the latter's Airband initiative – that the raw performance characteristics, the reliability, and the usability of the technology will only continue to improve.

To maximise bandwidth I recommend that link height and distances are limited and that manufactures begin to adopt MIMO to increase the bandwidth per 8MHz channel rather than continually expanding aggregated channel capability.

In Kintyre and Inverness we saw how an 8MHz channel alone over short distances in relatively clean air can achieve high speeds.

The capability to aggregate non-contiguous channels is also a highly desirable feature. There are radio manufacturers working on this at the moment and it is certainly possible to achieve in other radio bands.

As a USO technology delivering 10Mbps there is no doubt that TV White Space has the mettle to solve the issue even without MIMO in very challenging environments.

In addition, there are dozens of applications the technology could assist with – from smart cities to smart rural, emergency services / disaster relief networks, ship to shore communication to name but a few.

As of recently there are five properties benefiting from much better broadband than before the pilot with TVWS links ranging from a solid 14Mbps to 70Mbps TCP.

In 1929 John Logie Baird first test broadcast for the BBC in Covent Garden. Only in the last few years has anybody found a hugely viable, practical and automated solution to unlock hundreds of MHz of unutilised spectrum.

I believe this demonstrates that a Spectrum Sharing philosophy is totally viable even if the rules around certain parts of the regulations are not perfect. What has been achieved with TVWS is ground-breaking from a technical and regulatory framework perspective. With further work the sky's the limit and I hope in some small part of the work in this pilot has positively contributed to that aim.

18. 60GHz Mesh Networking

A reminder of the two questions that were posed at the beginning

- Question 1: Should 60GHz technology be considered at all for rural deployments?
- Question 2: Does new point to multipoint / mesh technology offer any benefits in a rural environment?

18.1. Hardware Selection Process

Broadway Partners decided to test a 60GHz Mesh radio following an extensive rescoping session with DCMS.

During our pilot we experienced hardware shortages of TV White Space equipment and at the same time Ofcom announced ground breaking changes in 60GHz regulation that would enable the technology to be utilized Point-to-Multipoint.

This was significant because it meant extremely high capacity radio can be utilized over relatively short distances aggregated to a single device. Rather than having a P2P link with a dish at each end to every end point, a “sector” style device could be utilised to aggregate the connections.

In 2017, I met CCS at Mobile World Congress in Barcelona and I was impressed with their work on mesh networking technologies but could not utilize their radio due to spectrum licensing constraints.

With 60GHz there are no licensing constraints. As the mesh chip was essentially already developed and had been tested in lower bands I wanted to see what would happen in the higher frequency bands and began to make enquiries.

18.2. Lab Deployment

Before deploying in the field we always test in a controlled environment. In this case the network was tested utilizing non-penetrating roof mounts in Liverpool point-to-point.

The network was initially configured with the help of CCS using command line in our office and then carried down the road and tested. Each radio was confirmed working at a range of approximately 20 metres. The entire process took around 4 hours – from unboxing to packing away.

The test involved a simple UDP iPerf test. We did not attempt to align antennas or improve link performance. Everything worked and we initiated pilot scoping from that point.

18.3. Live Test Area

Llanddewi Rhydderch is a village in the Welsh county of Monmouthshire. Llanddewi Rhydderch is known for many positive things - the locals are welcoming, forward thinking and have a very strong community spirit.

The village is also known for having some of the worst broadband in the area. The villagers themselves have spent a lot of time trying to get superfast broadband. There have been visits from small local ISPs to Welsh Government representatives and everything in between. They have in short tried everything imaginable.

Responding to the request for assistance from the local Rural Development team and in particular Michael Powell of Monmouthshire County Council, Broadway set about supplying the village with broadband whilst overlaying the CCS equipment in an attempt to give the village a Gigabit boost.

18.4. Introduction to CCS Metnet 60 GHz

Metnet is the world's first fully self-organising mmWave backhaul system. Metnet 60GHz Nodes connect autonomously to form flexible MPtMP (mesh) self-organising (SON), self-healing links that dynamically reconfigure to optimise performance and spectral efficiency as LOS or NLOS circumstances or traffic levels change. The CCS Metnet system enables mmWave deployment in a flexible, organic way allowing customers to start small and grow as they go.

Applications include:

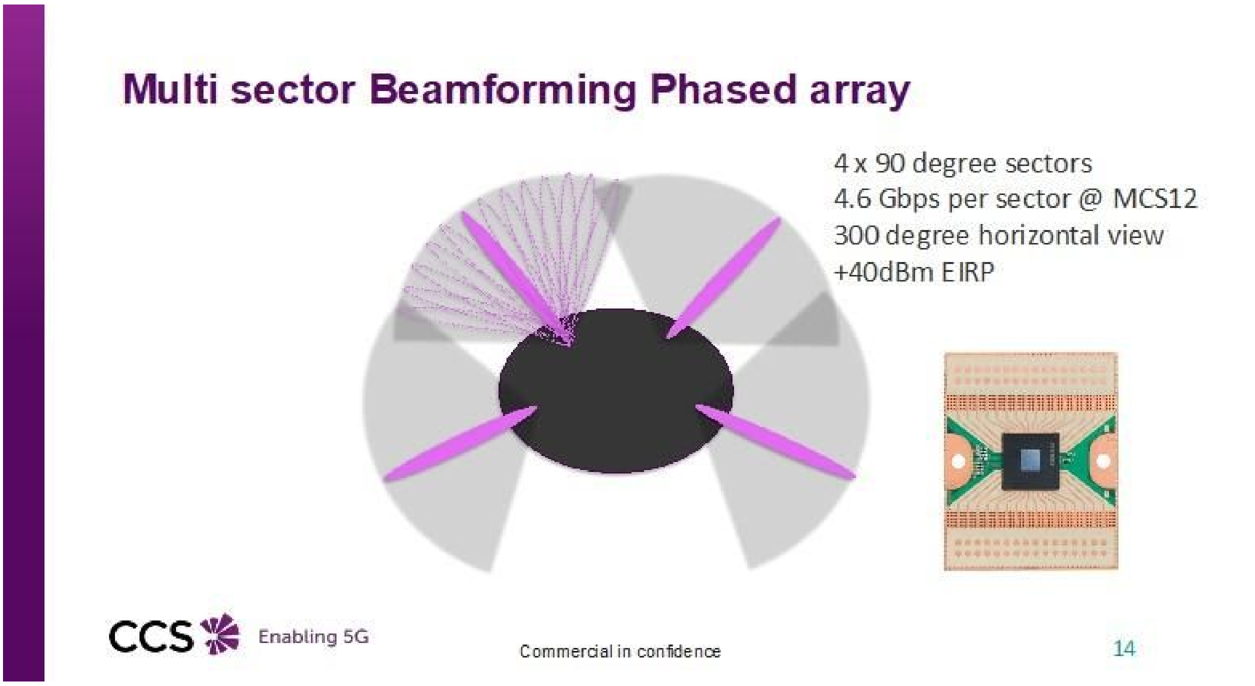
- Small-cell backhaul
- FWA and enterprise connectivity
- CCTV backhaul
- WiFi backhaul
- Fibre extension/protection

The CCS self-organizing unlicensed mmWave 60GHz system is designed for deployment on street furniture (such as lampposts or houses in the case of FWA) below the roofline using license-free spectrum. Each unit has four integral radios each covering a 90º area, overlapped to give a 300º horizontal area of total coverage. The unit uses a space/time switching schedule to form a Self Organising Network eliminating the need for frequency planning. This means the operational expense of designing, deploying and expanding a wireless network is minimised.

Figure SEQ Figure * ARABIC 2 - Metnet Node

The system uses beamforming steerable antennas, interference monitoring and dynamic self-organisation to optimise end-to-end performance and provide link redundancy.

The system is designed to support 57GHz-66GHz band (57GHz-71GHz is a future option). The frequency band is split in 2.16GHz channels supporting data rates greater than 3Gbps giving total throughput of greater than 12Gbps with 4 channels. Metnet 60G delivers a 60GHz solution with switching capacity of 12Gbps, low latency and self-organisation capabilities. Use of innovative steered beam phased array technology will enable 3Gbps to each end-point, operating in unlicensed spectrum band, with proprietary interference avoidance technology to manage coordination and co-existence with other 60GHz systems.



On the current deployment EIRP is currently limited to +38dBm for the current hardware revision in order to meet ETSI 99% bandwidth approvals.

Metnet 60GHz will allow QoS and carrier class synchronisation whilst operating in high-interference environments. Comprising discreet and aesthetic units to remove planning issues, the Metnet 60GHz system offers a uniquely high-performing solution for enterprise connectivity, residential FWA, small-cell mobile backhaul, fibre extension and smart city IoT.

Each Node has a wide 300-degree field of view, so only one unit is required per site, rather than multiple radios. There's no need for any manual alignment and each Node supports multiple connections for higher resilience.

The Nodes polls the network continually and automatically determines the optimal topology to deliver capacity where needed.

18.5. Llanddewi Rhydderch Pilot

18.5.1. Network Topology - Backhaul Network

The backhaul is located just 2km as the crow flies in a neighbouring village of Llanvapely. Unfortunately, because of the topography Broadway had to build 3 MM Wave 80GHz links to navigate around hills to supply over 1Gbps into the village. A total distance of 8km.

(image removed)

18.5.2. The CCS Metnet Network

As illustrated in the diagram below, the Llanddewi Rhydderch network consists of four CCS Metnet 60 GHz Nodes deployed in a point-to-multipoint topology. The "Wired" Node (B52 label) is physically located at the PoP site which serves as the demarcation point between the Core Network (i.e. Fibre connectivity to local data centre) and the CCS Metnet mesh network. Each Node has a 300-degree horizontal field of view and corresponding Line of Sight (LOS) to at least two neighbouring Nodes as represented in the LOS map below providing a layer of resiliency in the event of the loss of one remote site (e.g. local power failure, LOS obstruction, etc.):

(image removed)

18.5.3. Frequency Allocation

The CCS Metnet 60 GHz Node has four radios supporting individual channel sizes of approximately 2 GHz in the unlicensed 57GHz - 66GHz bands in compliance with the UK Ofcom IR2030.

The installed Node's hardware revision supports channels 1-4 whilst the next hardware version will support channels 1-6.

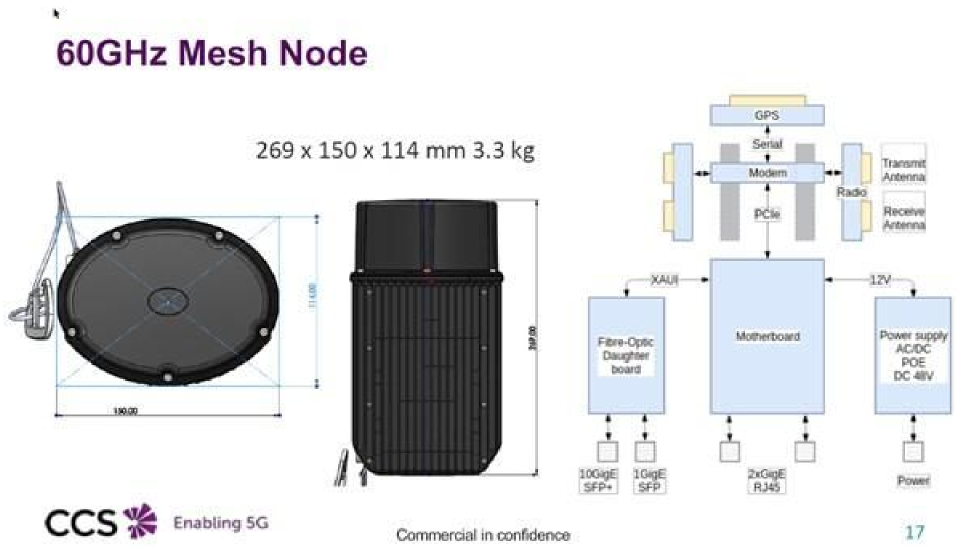
Channel	Centre GHz	Min GHz	Max GHz	Bandwidth GHz	O2 Absorption dB/km
1	58.32	57.24	59.4	2.16	12.91
2	60.48	59.4	61.56	2.16	15.01
3	62.64	61.56	63.72	2.16	12.25
4	64.8	63.72	65.88	2.16	4.36
5	66.96	65.88	68.04	2.16	1.1
6	69.12	68.04	70.2	2.16	0.44

18.5.4. 802.11ad – WiGig Standard

The Metnet Nodes are based on the IEEE 802.11ad standard utilizing the 60 GHz frequency for WiGig networks. Each link consists of a PBSS Central Point (PCP) which provides centralized scheduling, interference management and timing using beacons (i.e. superframe) and a station (STA), i.e. 802.11ad client. Each STA finds the optimal antenna configuration with its neighbouring PCP using a two phase beamforming training process, sector selection and fine tuning.

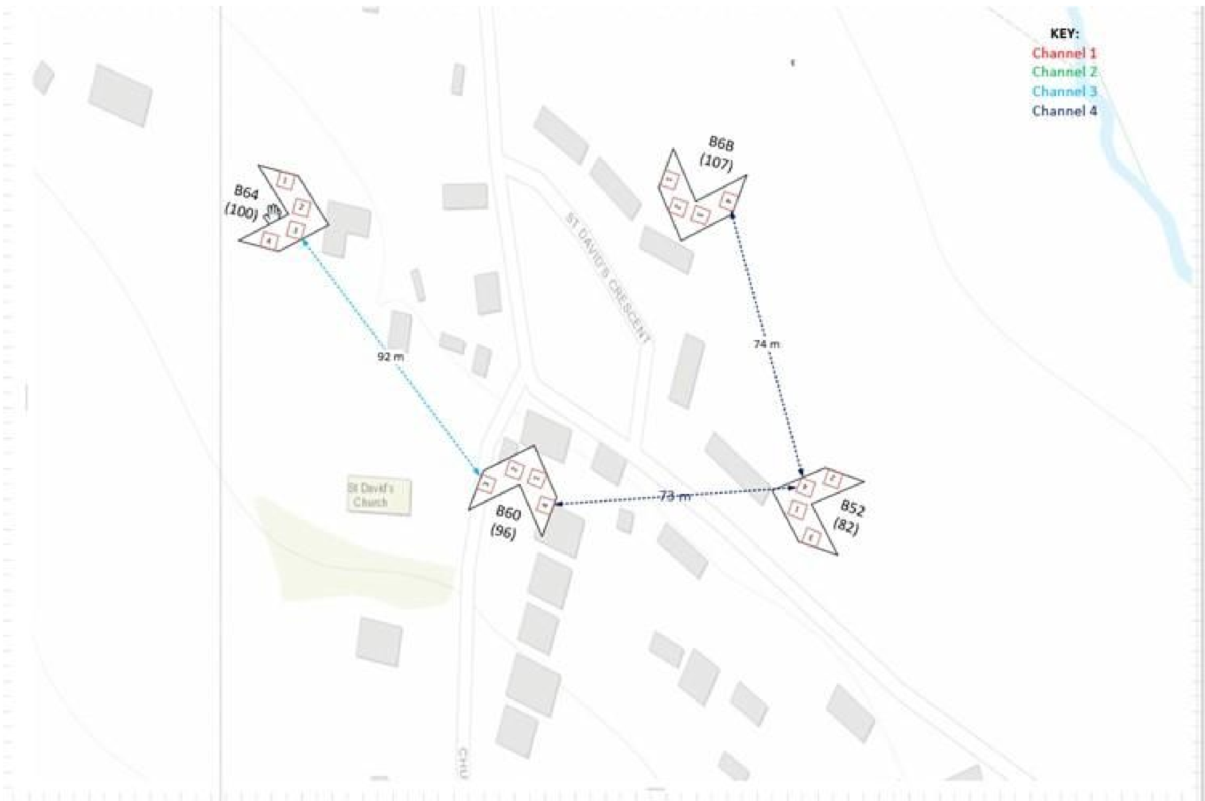
18.5.5. CCS Metnet 60 GHz Mesh Node

The Metnet system comprises small, lightweight and robust units for discreet installation on street furniture, sides of buildings/houses and roofs. Each multipoint Node has a wide 300-degree field of view, so only one unit is required per site, rather than multiple radios required by PtP solutions. This is not only more acceptable to urban planners, but contributes significant CAPEX and OPEX savings. See the below illustrations of the Node and its external ports.



18.5.6. Network Performance

Following the physical installation of the Nodes, the Nodes were powered and automatically self-organised into the topology as illustrated below without the need for frequency planning or antenna alignment.



All links achieved MCS 9 which equates to 3 Gbps in terms of radio capacity.

The current node capacity is restricted to approximately 600-700 Mbps by the software switching function of the Node. When the new firmware is released hardware switching will be introduced. This is expected during the project extension phase in April which aligns the Node capacity with the radio capacity.

In addition, a link preference feature should offer channel/radio diversity for point to multipoint topologies, which essentially means even more bandwidth.

The table below shows MCS vs capacity and was performed by CCS.

MCS	Mod	FEC	SNR dB	RSL min dB	L1 Gross Rate (after FEC) Mbps	L2 Line Rate Mbps
0	DSSS	12	-11	-84.52	28	22.4
1	BPSK	1/2	-0.2	-73.72	385	308
2	BPSK	1/2	1	-72.52	770	616
3	BPSK	5/8	2.2	-71.32	963	770.4
4	BPSK	3/4	3.6	-69.92	1155	924
5	BPSK	13/16	4.5	-69.02	1251	1000.8
6	QPSK	1/2	3.8	-69.72	1540	1232
7	QPSK	5/8	5.3	-68.22	1925	1540
8	QPSK	3/4	6.8	-66.72	2310	1848
9	QPSK	13/16	7.9	-65.62	2503	2002.4
10	16QAM	1/2	10.1	-63.42	3080	2464
11	16QAM	5/8	12	-61.52	3850	3080
12	16QAM	3/4	14.1	-59.42	4620	3696

18.5.7. iPerf Testing of Deployed Links

In order to qualify the throughput to each site, iPerf was utilized running on a laptop connected to the 1Gbps external copper port of the Node.

Scenario	Test Run	DL/UL	iPerf Configured Bandwidth (Mbps)	iPerf Server Report Bandwidth (Layer 4)	Ethernet Layer 2 Bandwidth (~ equivalent)	Total Ethernet Layer 2 Bandwidth (~ equivalent)	Packet Loss (%)
1	Test 1	B52 - B6B	300	271	282	563	9.60
		B6B - B52	300	270	281	563	9.90
	Test 2	B52 - B6B	250	245	255	509	2.10
		B6B - B52	250	244	254	509	2.40
	Test 3	B52 - B6B	400	339	353	457	4.30
		B6B - B52	100	100	104	457	0.00
2	Test 4	B52 - B64	300	285	296	573	4.90
		B64 - B52	300	266	277	573	11.00
	Test 5	B52 - B64	250	244	254	506	2.20
		B64 - B52	250	242	252	506	3.10
	Test 6	B52 - B64	400	350	364	468	3.00
		B64 - B52	100	100	104	468	0.00

The hardware switching feature will be introduced in the April software release which aligns the Node capacity with the radio capacity.

The current node throughput (e.g. 500-600 Mbps) observed is somewhat less than internal CCS testing (e.g. 600-700 Mbps) and further investigation is scheduled.

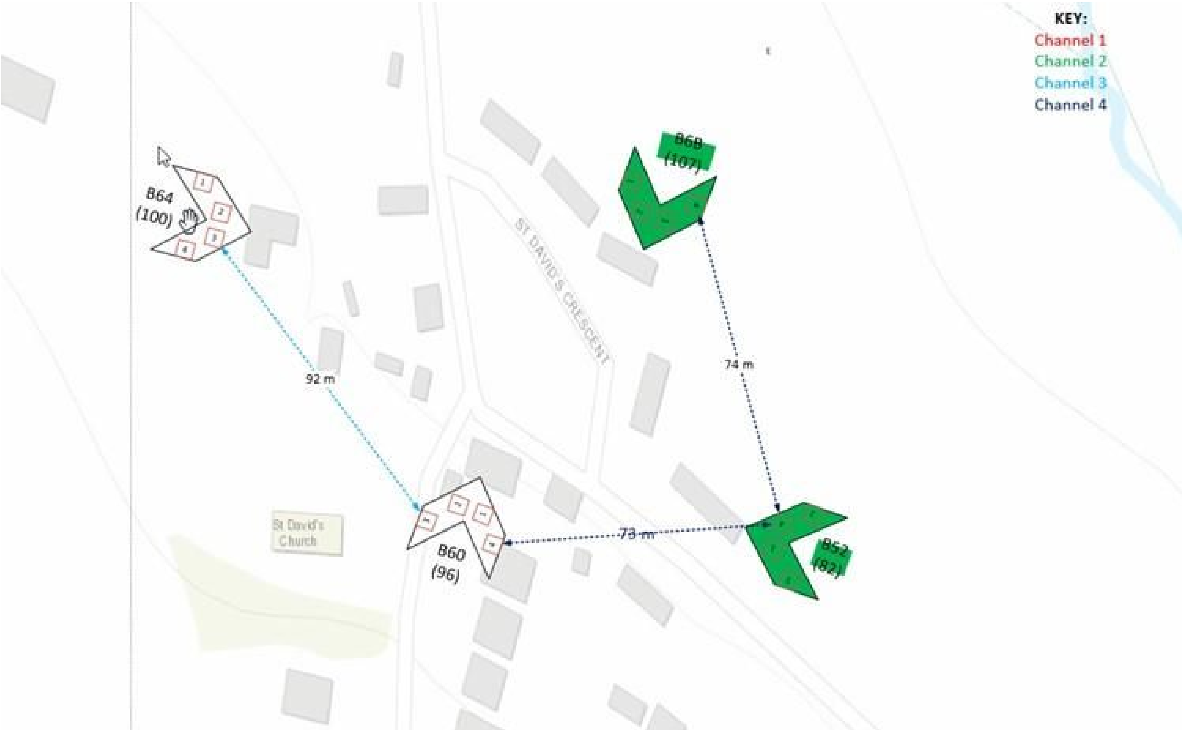
At the moment we do not know if this discrepancy relates to test equipment, topology or other factors affecting Node CPU performance but, regardless, the node throughput performance will improve dramatically following the introduction of hardware switching and further optimizations to the MAC. Before carrying out more extensive testing we will wait for the software release and report again at the end of the project extension.

More throughput testing should be performed once the Nodes are upgraded and CPE WLAN router is upgraded from FastEthernet to Gigabit Ethernet.

Because of the very high speeds we will not use iPerf with laptops and will test over fibre test equipment and will design a better test.

18.6. Test Scenario 1

iPerf test from base to client point to point.



18.6.1. iPerf results from B6B Node

Symmetric test:

```
c:\iperf>iperf -c 192.168.219.73 -p 5001 -u -b 300M -t 120
------------------------------------------------------------
Client connecting to 192.168.219.73, UDP port 5001
Sending 1470 byte datagrams, IPG target: 39.20 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.145 port 59940 connected with 192.168.219.73 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  4.19 GBytes   300 Mbits/sec
[  3] Sent 3061209 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  3.78 GBytes   270 Mbits/sec   0.029 ms 302862/3061209 (9.9%)

c:\iperf>
c:\iperf>
c:\iperf>iperf -c 192.168.219.73 -p 5001 -u -b 250M -t 120
------------------------------------------------------------
Client connecting to 192.168.219.73, UDP port 5001
Sending 1470 byte datagrams, IPG target: 47.04 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.145 port 62637 connected with 192.168.219.73 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  3.49 GBytes   250 Mbits/sec
[  3] Sent 2550980 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  3.41 GBytes   244 Mbits/sec   0.706 ms 60718/2550980 (2.4%)

c:\iperf>
```

Asymmetric test:

```
c:\iperf>iperf -c 192.168.219.73 -p 5001 -u -b 100M -t 120
------------------------------------------------------------
Client connecting to 192.168.219.73, UDP port 5001
Sending 1470 byte datagrams, IPG target: 117.60 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.145 port 56701 connected with 192.168.219.73 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  1.40 GBytes   100 Mbits/sec
[  3] Sent 1020405 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  1.40 GBytes   100 Mbits/sec   0.117 ms   93/1020405 (0.0091%)
```

18.6.2. iPerf results from B52 Node

Symmetric test:

```
c:\iperf>iperf.exe -c 192.168.219.145 -p 5002 -u -b 300m -t 120
------------------------------------------------------------
Client connecting to 192.168.219.145, UDP port 5002
Sending 1470 byte datagrams, IPG target: 39.20 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.73 port 60777 connected with 192.168.219.145 port 5002
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  4.19 GBytes   300 Mbits/sec
[  3] Sent 3061190 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  3.79 GBytes   271 Mbits/sec   0.027 ms 293075/3061190 (9.6%)

c:\iperf>iperf.exe -c 192.168.219.145 -p 5002 -u -b 250m -t 120
------------------------------------------------------------
Client connecting to 192.168.219.145, UDP port 5002
Sending 1470 byte datagrams, IPG target: 47.04 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.73 port 54159 connected with 192.168.219.145 port 5002
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  3.49 GBytes   250 Mbits/sec
[  3] Sent 2551012 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  3.42 GBytes   245 Mbits/sec   0.281 ms 52831/2551012 (2.1%)

c:\iperf>
```

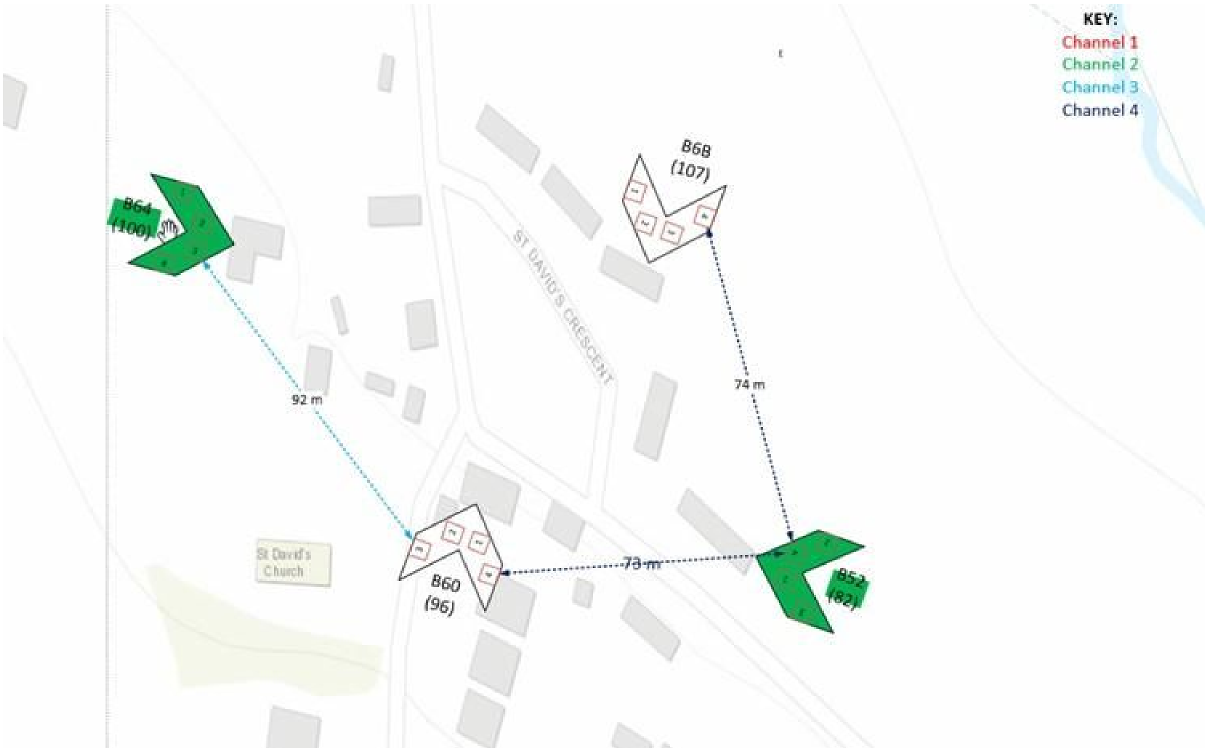
Asymmetric test:

```
c:\iperf>iperf.exe -c 192.168.219.145 -p 5002 -u -b 400m -t 120
------------------------------------------------------------
Client connecting to 192.168.219.145, UDP port 5002
Sending 1470 byte datagrams, IPG target: 29.40 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.73 port 52427 connected with 192.168.219.145 port 5002
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  4.95 GBytes   355 Mbits/sec
[  3] Sent 3619163 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  4.74 GBytes   339 Mbits/sec   0.228 ms 155555/3619163 (4.3%)

c:\iperf>_
```

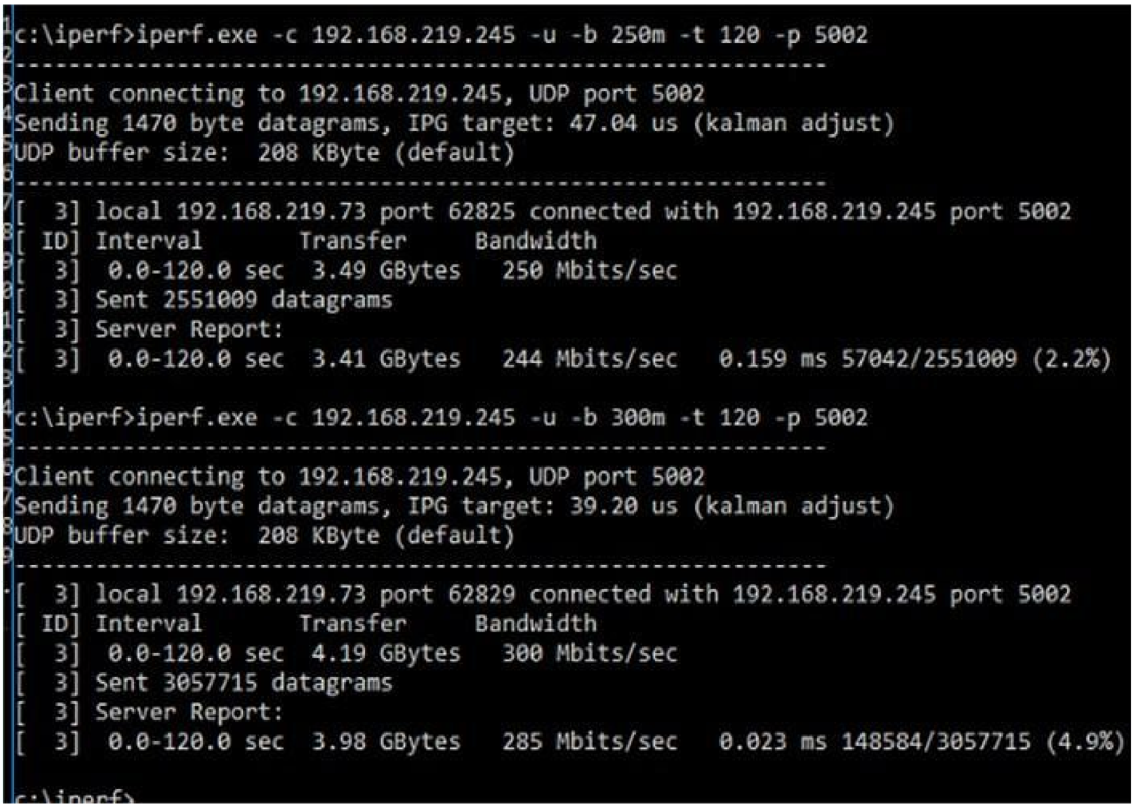
18.7. Test Scenario 2

iPerf test from base to client through B60 utilising the wireless mesh.



18.7.1. iPerf results from B52 Node

Symmetric test:

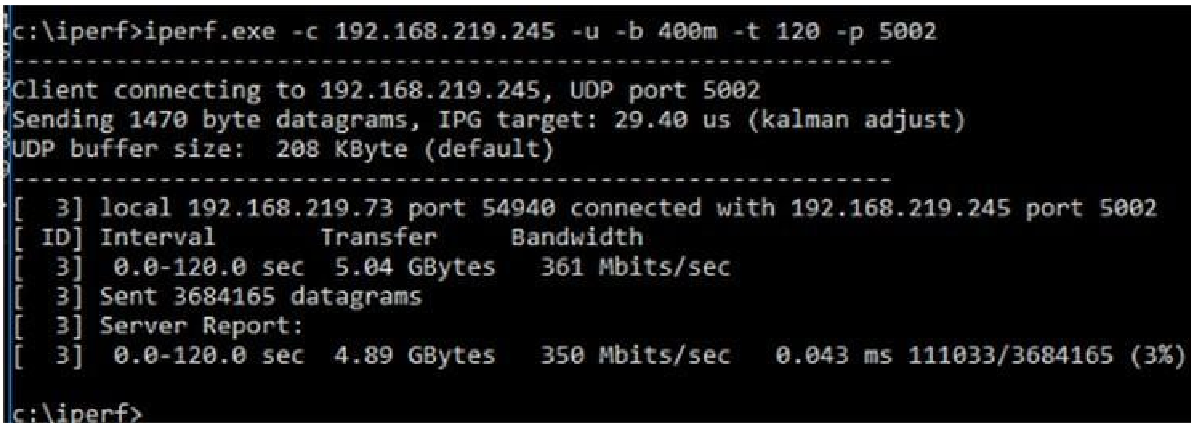


```
c:\iperf>iperf.exe -c 192.168.219.245 -u -b 250m -t 120 -p 5002
------------------------------------------------------------
Client connecting to 192.168.219.245, UDP port 5002
Sending 1470 byte datagrams, IPG target: 47.04 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.73 port 62825 connected with 192.168.219.245 port 5002
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  3.49 GBytes   250 Mbits/sec
[  3] Sent 2551009 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  3.41 GBytes   244 Mbits/sec   0.159 ms 57042/2551009 (2.2%)

c:\iperf>iperf.exe -c 192.168.219.245 -u -b 300m -t 120 -p 5002
------------------------------------------------------------
Client connecting to 192.168.219.245, UDP port 5002
Sending 1470 byte datagrams, IPG target: 39.20 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.73 port 62829 connected with 192.168.219.245 port 5002
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  4.19 GBytes   300 Mbits/sec
[  3] Sent 3057715 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  3.98 GBytes   285 Mbits/sec   0.023 ms 148584/3057715 (4.9%)

c:\iperf>
```

Asymmetric test:



```
c:\iperf>iperf.exe -c 192.168.219.245 -u -b 400m -t 120 -p 5002
------------------------------------------------------------
Client connecting to 192.168.219.245, UDP port 5002
Sending 1470 byte datagrams, IPG target: 29.40 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.73 port 54940 connected with 192.168.219.245 port 5002
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  5.04 GBytes   361 Mbits/sec
[  3] Sent 3684165 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  4.89 GBytes   350 Mbits/sec   0.043 ms 111033/3684165 (3%)

c:\iperf>
```

18.7.2. iPerf results from B64 Node

Symmetric test:

```
c:\iperf>iperf.exe -c 192.168.219.73 -u -b 250M -p 5001 -t 120
------------------------------------------------------------
Client connecting to 192.168.219.73, UDP port 5001
Sending 1470 byte datagrams, IPG target: 47.04 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.245 port 61008 connected with 192.168.219.73 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  3.49 GBytes   250 Mbits/sec
[  3] Sent 2551006 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  3.39 GBytes   242 Mbits/sec   0.055 ms 78233/2551006 (3.1%)

c:\iperf>iperf.exe -c 192.168.219.73 -u -b 300M -p 5001 -t 120
------------------------------------------------------------
Client connecting to 192.168.219.73, UDP port 5001
Sending 1470 byte datagrams, IPG target: 39.20 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.245 port 61011 connected with 192.168.219.73 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  4.19 GBytes   300 Mbits/sec
[  3] Sent 3061199 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  3.72 GBytes   266 Mbits/sec   0.041 ms 343565/3061199 (11%)

c:\iperf>
```

Asymmetric test:

```
c:\iperf>iperf.exe -c 192.168.219.73 -u -b 100M -p 5001 -t 120
------------------------------------------------------------
Client connecting to 192.168.219.73, UDP port 5001
Sending 1470 byte datagrams, IPG target: 117.60 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.219.245 port 53538 connected with 192.168.219.73 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0-120.0 sec  1.40 GBytes   100 Mbits/sec
[  3] Sent 1020404 datagrams
[  3] Server Report:
[  3]  0.0-120.0 sec  1.40 GBytes   100 Mbits/sec   0.242 ms   80/1020404 (0.0078%)
```

18.8. Possible Deployment Scenarios

It is clear that, over short distances, the technology works well and we are all looking forward to the new software release in April.

When we think of rural some people instantly think of a remote property in the Outer Hebrides clinging to a rock. The fact is there are lots of clusters of properties in rural locations that could be serviced extremely quickly with this type of backhaul and access technology.

Llanddewi Rhydderch had been waiting years for a solution and the villagers had tried everything imaginable.

We managed to deploy in less than eight weeks – which is a powerful capability. We could not have done this without the help of local landowners, the village and local council but from a technology perspective nothing else was viable and it worked.

You do not have to look particularly hard to find good deployment examples of potential Metnet deployments in rural environments.

This is the village of Llanarth in Monmouthshire which is another good example of a Metnet candidate deployment:

Just down the road from Llanarth is the village of Great Oak:

Both Llanarth and Great Oak are 'on net' already with Broadway Broadband so upgrading backhaul links to MM wave is straightforward.

During the pilot selection phase CCS and Broadway had considered other areas of the country. Here are some Scottish candidates on the Isle of Arran:

Here is another village called Blackwaterfoot on the Isle of Arran:

18.9. NLOS

Whilst 60GHz spectrum is highly susceptible to environmental clutter such as trees there are NLOS deployment capabilities that the mesh feature of the Metnet Node allow.

19. 60GHz Q 1 & 2 - Answer

Question 1: Should 60GHz technology be considered at all for rural deployments?

Question 2: Does new point to multipoint / mesh technology offer any benefits in a rural environment?

I think that already we can confirm that yes, 60GHz technology has a significant role to play in rural 5G; and can play a significant role in fulfilling the UK Government's ambition to bring gigabit-capable networks to 33 million homes by 2033 – and far sooner. We have seen the NLOS capabilities of Mesh and how we can move around objects, creating resilient infrastructure.

Subject to manufacturers achieving the kind of unit price reduction seen in other chip-based technologies, the economic model makes complete sense as either a permanent full access solution or as means to a final deployment of fibre.

There is already a lot of fibre in many areas thanks to the success of government funded fibre to the cabinet deployments.

Getting from the cabinet to properties and businesses at gigabit speeds can be achieved with pure fibre but it can be in conjunction and faster with a mix of fibre and radio.

My opinion is that the solution to rural 5G lies in utilising any and all technology that is available to achieve the fastest speeds with the lowest latency possible quickly and cost effectively.

There is a significant opportunity to radically increase traction by expanding fibre networks using new high capacity radio in the backhaul and access network.