5G Rural Integrated Testbed

D5.3 Final Report - Broadband

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1 EXECUTIVE SUMMARY

This report reviews and summarise the final findings and conclusions drawn throughout the past 18 months working in partnership with consortium members, suppliers and most importantly, potential users.

It reviews the technology use case activities selected for the trial, circumstances, geography, and use cases for their deployment, the relative success levels, lessons learned and present an outlook for future deployment, to answer the question regarding a plan to inform government how 5G technologies could facilitate the move towards a 100% connected Britain.

Two different technologies were trialled by two project partners.

TV White Space (TVWS) uses the spectrum which used to carry the analogue TV signals. It should be suitable for rural locations because it can carry signals over long distances and pass easily through trees etc. Unfortunately, the trials found that the equipment currently available in the market suffers from significant interference from noise from other services particularly from TV masts and a reliable broadband signal cannot be delivered. One partner (BP) did find a stable application, but this was using a distance of only a couple of km and in an area where the interference from other services was almost non-existent.

Millimetre wave (60 GHz) did work well at all the trial sites, but has a very limited range and so requires an extensive network to cover an area. However, it was particularly successful with a network in a remote area which had a very high density of bandwidth hungry users.

The primary conclusion found was that although 5G might offer solutions for delivery of rural broadband, the TVWS equipment currently available on the market cannot deliver the range or service levels required.

2 INTRODUCTION

This report combines the outputs of trials conducted on the 5GRIT project by two partners, Quickline Communications Ltd (QL) and Broadway Partners Ltd (BP) as part of the 5G Testbed and Trials Programme funded by the Department for Digital, Culture, Media and Sport. Both partners worked on similar trials to prove the suitability of 5G to deliver broadband in rural areas, but they used different equipment manufacturers, in different parts of the UK, with substantially different geography and topography. The monitoring of both Quickline and Broadway Partners trials was conducted by Lancaster University.

This report builds upon the report which was delivered at the end of Phase 1, and although the key findings of Phase 1 are included below, more details are provided in the Phase 1 report.

The Phase 2 work by the two partners had different objectives:

- BP were delayed in the building of their networks in Phase 1 and they wanted to run more extensive evaluations of the performance and sustainability of these networks (in conjunction with the monitoring service provided by Lancaster University).
- QL had some further evaluation trials to run with equipment provided by alternative manufacturers but also to build a new network in an area of intense service demand, but which had no extant service. The objective being to determine if 5G could deliver a quality service in this extreme test area.

In summary:

- The BP trials proved successful
- The new equipment evaluated by QL functioned as poorly as the original tests
- The intense use tests proved a great success

2.1 Background to Need

The quality of internet speeds across the world are dependent on the technology infrastructure of each country. Several published reports warn that the digital divide separating developed and developing countries is in danger of becoming a chasm, but also within a country in its own right. This widening digital divide creates a multi-tier system – where those that have connectivity can access digital services and develop faster and feel more included than those that cannot.

This split has significant socio-economic implications reinforcing the hindrance of progress. This divide could not only emerge but become entrenched because of the deepening inequality in connectivity between starters, adopters and front-runner organisations and technologies. Reports and industry highlight the issue of internet connection speeds as directly correlated to the quality of technology infrastructure within each given country. Large gaps in connectivity persist, mainly due to the lack of infrastructure, affordability, and lack of skills; this project has attempted to redress these imbalances with a series of trials, use cases and testbeds to determine how this digital divide could be narrowed and moves towards its potential closure.

3 RESEARCH QUESTION - WHAT WE SET OUT TO ACHIEVE USING TVWS

Can 5G deliver 30Mbps broadband compliant with BDUK's state aid requirements in rural areas at scale?

Selection criteria (manufacturer, stock availability, geography, topography, extant customer base etc) for any technology trial can prove to be difficult given its limited availability, having to take into account several aspects for consideration.

The nemesis of fixed wireless access [FWA] equipment is well documented to be, but not limited to ground clutter or terrain obstacles. Any such element which bisects the line of sight [LOS] signal between base station and the customer premises can disrupt the signal and impede in the quality of the connection. 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 the quality of the signal, lowering the quality of experience.

For example, on demand streaming services would be greatly affected. It can also lead to experiences of exclusion and inability to use the services which in a connected world have become commonplace.

3.1 Network Locations

Figure 1 shows the locations of the QL network used in Phase 1 & 2.

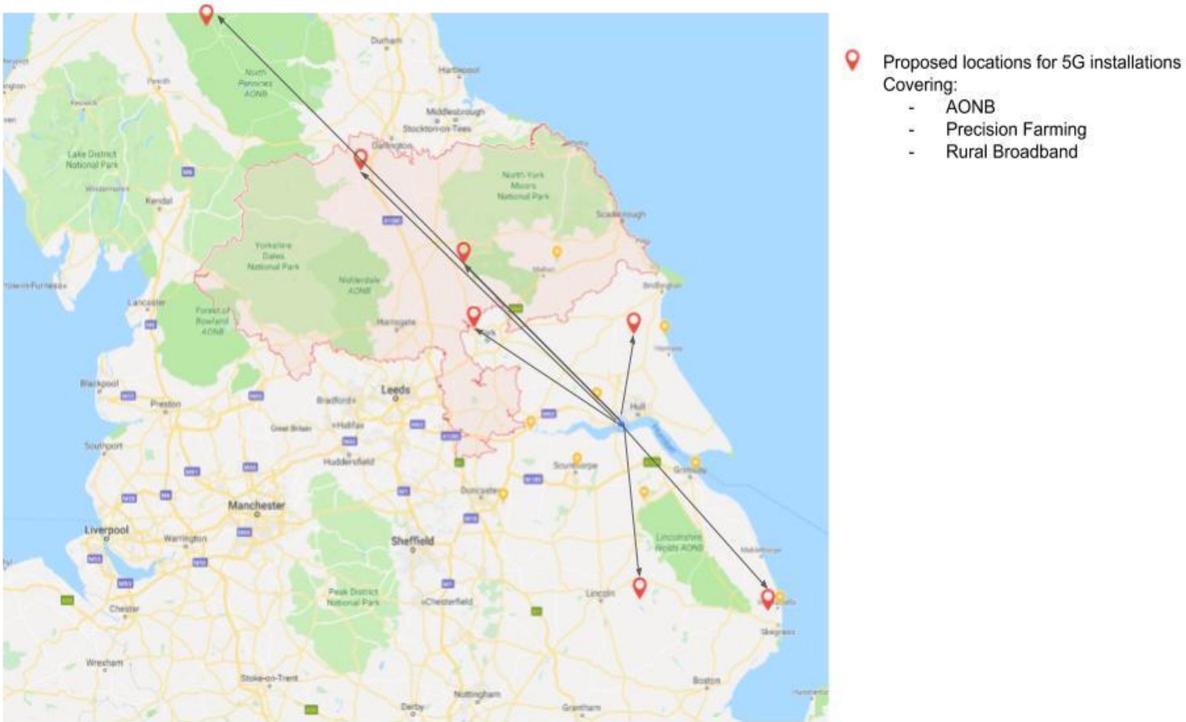


Figure 1

3.2 QL - TVWS

3.2.1 Equipment

At the start of the project, equipment supply for TVWS was limited to working with 6Harmonics, operating from Canada; setting aside the time differential the working relationship developed well throughout the project to try to understand the capabilities and limitations of the technology, against the requirements in the UK given the difficulties encountered using traditional FWA. However, the delay between equipment ordering, and its delivery into the UK of approximately 3-4 weeks proved to be a strain on project momentum; there was a learning to incorporate the equipment supply into project timescales and predict the next ordering cycle.

Having had several years' experience undertaking FWA installations Quickline has assimilated examples from which it can draw criteria on which to base a selection for a geographical area, which proved to be a useful candidate for 5G trials. The location of rural communities being geographically separated from internet-based services can only add to the digital divide. For the purposes of this trial the equipment selection criteria was limited to using TVWS and 60GHz technologies, installed across differing locations throughout Phase 1 of the trial, that being April 2018 to March 2019.

Throughout the technology evaluation period of Phase 1 (MS1-MS3) it became apparent that these the field based trials, clearly demonstrated that the software and functionality suite of management utilities per technology set required significant further development and enhancement. For example, a lack of basic Simple Network Management Protocol – SNMP: although it is expected that these issues will be resolved in future hardware / firmware releases, these were not available during the trial period.

Location 1 - Longhills

Longhills [Figure 2] in Lincolnshire, was selected as a testbed based on two criteria, the location and the use cases as declared at the project offset. The former represented a good example of a community struggling to obtain a broadband connection above 1-2 Mbps, which would be considered a poor internet use experience. See below the location of CPE equipment at Longhills, note the terrain clutter, in this case trees, which has traditionally been a degrading factor for fixed wireless solutions; in this use case the test would be location but also the use cases for end users, such as local businesses, educational purposes, and the inclusion factors for all age groups making up this collective.

Figure 2

3.2.2 Summary of initial installation trials - July 2018

In order to understand the capabilities and limitations of the trial it was necessary to first identify a site which had previously demonstrated issues when trying to use traditional FWA connectivity technology options. It would seem therefore logical to revisit such locations and retry using TVWS technologies. The following is a summary of the trials.

As the crow flies between Bardney base station [BS] and Longhills customer premise equipment [CPE] there is a distance of approx 5/6 miles in line with TVWS distance limitations; along this route there is no clear line of sight [LOS] and much terrain clutter; the two conditions which we would be testing as part of this initial trial.

The TVWS CPE equipment was first validity tested in close proximity to the BS to ensure it was operational, at a range of approx. 1 mile with clear line of sight using multiple bonded channels to increase the bandwidth on offer to reach 30Mbps. The results of this initial set-up test proved successful using a single channel broadcast we were able to obtain firstly connectivity, but secondly with a speed throughput measuring 26 mbps - see below Figure 3 in evidence:

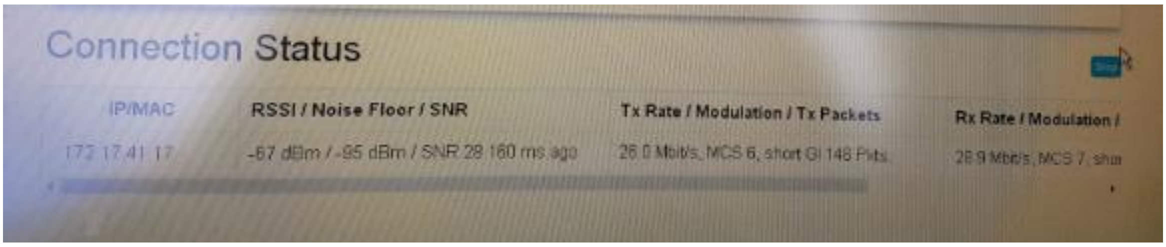


Figure 3

On the basis that the equipment was operational in the field, it was then appropriate to transport to the Longhills area, approx 5/6 miles as the crow flies to compare the achievable connectivity once distance and terrain clutter were introduced.

To clarify the field based installation criteria, the building was a mansion house approx 20 metres above ground level providing good clearance but surrounded by trees; the resulting Figure 4 shows the following:

Connection Status

IP/MAC	RSSI / Noise Floor / SNR	Tx Rate / Modulation / Tx Packets	Rx Rate / Modulation / Rx Packets	Radio Link Up Time
ac:ee:3b:03:80:a5	-84 dBm / -93 dBm / SNR 9 470 ms ago	2.6 Mbit/s, MCS 0 4 Pkts.	8.7 Mbit/s, MCS 2, short GI 4 Pkts.	0:0:1-0 d-0 m-0 y

Figure 4

Only for a very short period of time were we able to gain any kind of connection back to the BS; such was the infrequency of connectivity it was difficult to obtain any speed readings throughout the testing process. These results did not establish a useful / successful precedent for the trial.

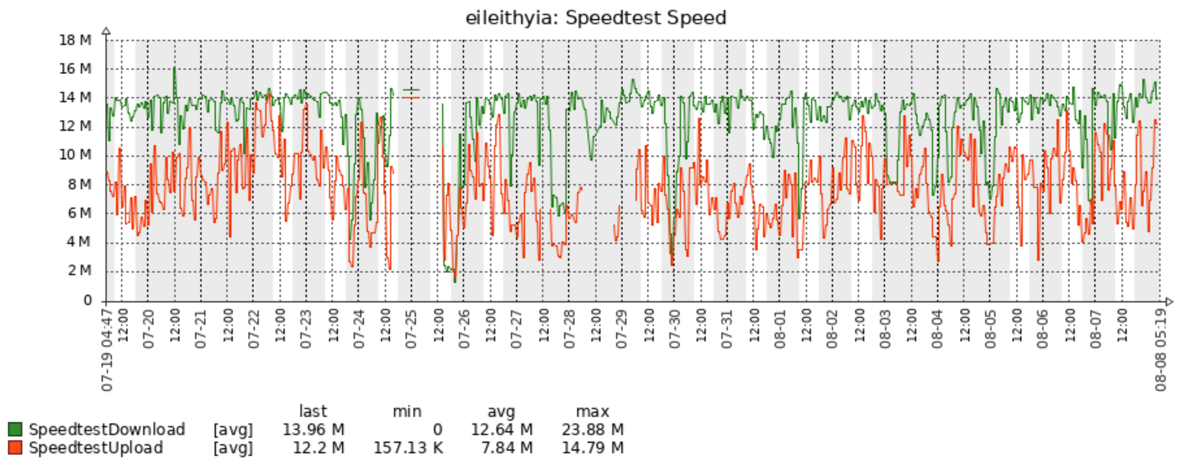


Figure 5

This graph demonstrates the throughput from a monitoring device at the customer premises in Bardney, to Ooklas speedtest servers over a period of 20 days in July 2019. As previously mentioned, there was a relatively high degree of instability, even when testing at a 5 minute resolution. This is demonstrated in the gaps in the graph, where a speedtest was performed but the data could not be sent back to Lancaster. Over the seven months Lancaster was monitoring the Bardney installation, an average of 11.37Mbit/s download throughput was observed and an average of 5.62Mbit/s was observed for upload.

Location 2 - Nenthead Mines

TVWS technologies were deployed between Mount Hooley and Nenthead Mines (Figure 6) and (Figure) to support the tourism apps by WAM and North Pennines AONB. The background behind this installation which was required to support elements of the tourism industry [WAM mobile app] has also been documented in previous reports. It is fair reflection that WAM reports an increase in localised searches in these designated areas since 5G enabled augmented reality elements of the application have been delivered. In this use case the capacity of the network seems to thus far be performing as desired, but the real test will be evident from increased footfall in the peak of the holiday season.

Figure 6

Figure 7

The data supplied by Lancaster University in Figure 8 supports this view in the speeds approaching superfast are attainable given the correct combination of technology, ground terrain and spectrum availability, certainly in respect of data gathered over a period of approximately two months. Over this period, the performance metrics can be seen to be very stable and comparable with wired VDSL networks. Although the speeds delivered falls just short of superfast at 27 Mbit/s, when combined with the low latency performance of less than 30ms this installation far outperforms any alternatives in the area.

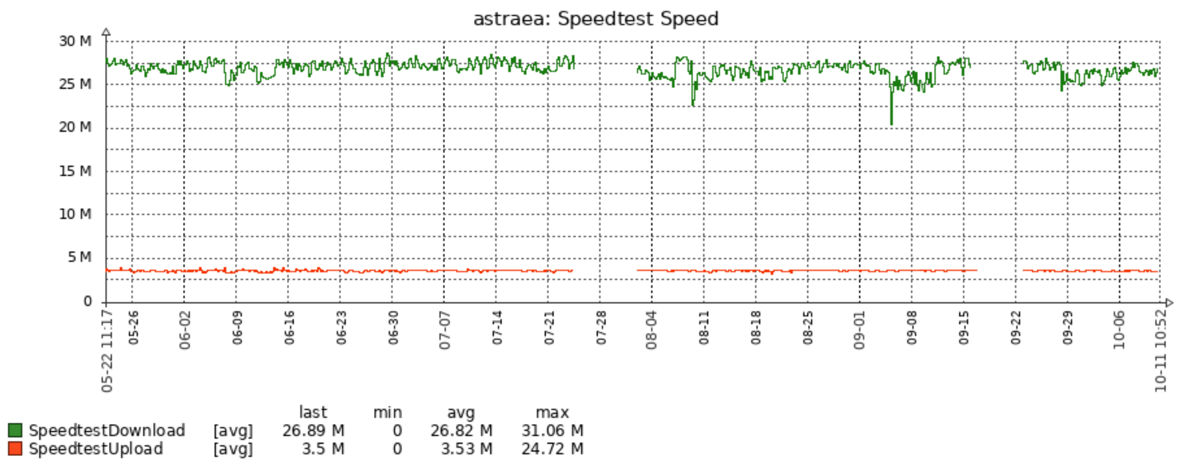


Figure 8

Figure 8 displays the throughput at Ninebanks youth hostel over a 2 month period, measured by Lancaster University. Although the average throughput is in excess of 35Mbit/s, the relative instability observed in the graph is likely due to backhaul losses not present in other installations.

Summary

The connection speeds at this TVWS connection show a higher level of throughput than what has been achieved elsewhere and serve as a quality benchmark, using dual bonded channels (16 MHz). It is therefore the recommendation in this particular case no further actions are needed as the connection appears to be capable of serving the requirements at this time. A further review will be expected to log usage throughout the coming holiday period through July, August and September 2019.

Location 3 - TVWS deployment at Ninebanks Youth Hostel

The final TVWS connection has been rolled out at Ninebanks Youth Hostel, shown Figure and Figure 10. The background for this installation was to determine whether multiple customer connections could be supported from one transmission point to ensure there is minimal service degradation. This installation will also support the tourism use cases and provide rural broadband into the hostel to support the use case requirements.

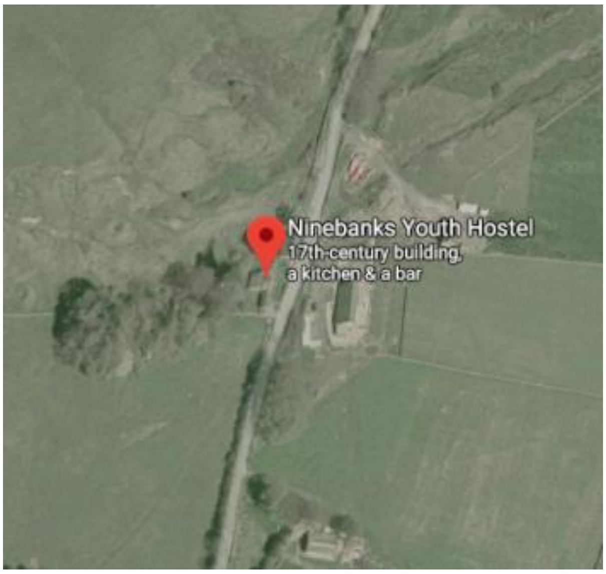


Figure 9

Figure 10

The LU evaluation determined that this connection is reaching superfast speeds despite the terrain, technologies deployed and spectrum availability in this area. From a customer perspective, QL has not yet received any adverse feedback relating to performance, but will continue to monitor the position throughout the forthcoming holiday season.

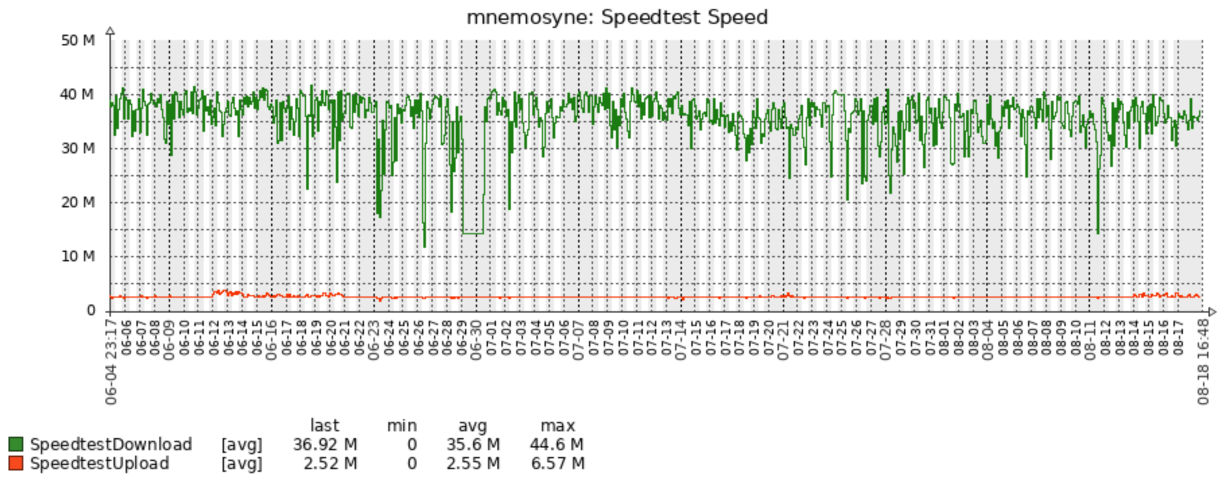


Figure 11

Figure 11 displays the throughput at Ninebanks youth hostel over a 2 month period, measured by Lancaster University. Although the average throughput is in excess of 35Mbit/s, the relative instability observed in the graph is likely due to backhaul losses not present in other installations.

Summary

Similar to the data provided by LU for Nenthead Mines, the connection speeds for this TVWS connection show a higher level of throughput than has been achieved elsewhere using dual bonded (16 Mhz) channels. It is therefore the recommendation in this particular case that no further actions are required. Over the past 2 months of monitoring statistics, the download speed of this link has exceeded NGA requirements with an average of 35 Mbit/s. The latency of this link is slightly higher than the latency recorded at Nenthead Mines (average round-trip time = 41.5ms). This is due to the number of hops in the link between Mount Hooley and the Ninebanks Hostel. There are also large spikes in the latency observed which again can be attributed to the number of wireless hops and their respective wireless technologies. In this use case the capacity of the network also seems to be performing well; again, the real test will be evident from increased footfall in the peak of the holiday season.

3.2.3 Key Learnings & Conclusions for TVWS Trial

Conclusions while disappointing have provided the following insight:

The combination of spectrum availability, distance and terrain clutter in this particular field trial determines the degree of success or otherwise.

- Any repeat trials in the areas will necessitate the identification of a BS nearer the residential area for CPE installation; given that ground clutter may also change it would seen a useful exercise to reposition the BS and repeat these tests and identify which factor changes have positively affected the outcome in regards to connectivity and stability.

- While this is disappointing for QL but more so for potential customers, the latter had been suitably briefed to advise that this might be a possible outcome, however the feedback from the customers remained positive and they welcome any subsequent news in terms of a retrial using differing technologies when they become available.
- The OFCOM spectrum suggested that multiple contiguous channels would be available in this area to connect a maximum of three and so attain a superfast +30Mbps connection; however, in reality only two contiguous channels were available for selection which limited the trial expectations and deliverables within the work packet. When connected to a maximum of ~20Mbps across the link was achievable. Extending this connection further still to between 6/8 CPE connections within the enclave, meant that the speeds attainable were significantly diluted, and in order to reach anything near a usable service, would mean that multiple TVWS BS to CPE connections would be required as part of a further trial, however it remains to be seen whether any local interferences would be generated from such a set-up.

3.2.4 Lessons Learnt

Communication

- Identify a local champion to act as a communication hub for the community.
- Provide clear background information to residents and communities regarding the technology being tested, depict the reason for its use and the hopes for achievement.
- Provide a story to the community with regular updates on build progress.
- Provide an update to the community on speed tests and service quality through the testing period.
- Provide community briefing showing the kit and the demonstration of how the kit utilises TV White Space and what is TV White Space

Equipment

- Demonstration of what the deployed equipment will look like and how it might impact the local horizon and buildings.
- Training on kit specifications, alignment and cabling to a wider range of engineers.
- Provision of installation kit that can be used as a self service installation to be considered.

Installation

- Time to deploy both base station and the customer connection were in line with the project projections.
- Install of the base station was in line with the installation process of similar NGA FWA.
- The installation of the customer equipment was described as slightly easier than a fixed wireless connection as the requirement for highly accurate directional delivery was less than with a fixed wireless connection.

- Reviews of the process would suggest that with the provision of some additional background / install training this equipment could be installed very simply by mid-level expertise installation engineers.

Overall Feedback

- Improve communications to community.
- Improve training on technology to deployment teams.
- Provide background on TVWS technology to alleviate any perceived health fears; referring to Public Health England as directed by DCMS with regard to 5G trials.
- Installation process was relatively straight forward.
- Speeds seen were low to average for non line of sight spectrum services when the aspiration was for much higher.
- Services were stable however suffered with adverse weather conditions such as wind and rain causing attenuation.
- This project work packet was devised to test how easy the TVWS equipment could be to deploy into a rural environment and whether this deployment would be able to deliver NGA qualifying services using non line of sight equipment.
- For each deployment location, it will be necessary to measure improvements served into the area against an established benchmark; working with the community to ensure that speed tests are taken pre and post TVWS technology set installation.
- Summarising view of this work packet is that the deployment of TV White Space equipment is suitable to be deployed by experienced fixed wireless engineers. Base stations and customer connections were proved to be without issue and service provision was good. At no time during the test period was work required to realign either base station nor customer antenna / aerial.
- Evidence supplied by Lancaster University in its monitoring capacity further supports these conclusions and has been documented in previous reports.
- ***Can 5G deliver 30Mbps broadband compliant with BDUK's state aid requirements in rural areas at scale?*** In regard to TVWS it could be summarised from evidence gathered throughout this trial, and so suggested that it is largely dependent on the combination of spectrum availability, distance, and ground clutter as evidenced in this report. Degrees of success varied are attainable and measurable however the degree of consistency and reliability remain under question for a mass rollout to try to attain a 100% connected Britain using TVWS.

3.3 BP – TVWS

During the first phase of the 5GRIT project, Broadway encountered two major delays which prevented the proper conclusion to the investigation:

- Supplier stock shortage
- Aa highly protracted re-scoping exercise.

Due to these delays, a short, limited, non-funded project extension was granted to gather additional information to support the outcomes of the various use cases.

In order to extend the trial period, Broadway agreed a set of terms with the original pilot customers that expired at the end of the original project.

3.3.1 Testbed Installations

During the project two TVWS connections were decommissioned. Both moved to alternative providers, one owing to the mounting position of the radio being unsuitable. The remaining connected customers are as follows:

- 1 X Inverness-shire TVWS (Dynamic Spectrum)
- 2 X Kintyre TVWS (Dynamic Spectrum)
- 4 X Monmouthshire Gigabit (60GHz Mesh)

3.3.2 Questions

The project extension sought to address the following areas:

1. Dynamic Spectrum - Antenna Array Improvements

The antenna array used for the HuWoMobility radio is quite large consisting of 2 flat Yagi antenna. This is sometimes problematic in very exposed areas such as the west coast of Scotland. We sought to test a smaller antenna array.

2. Dynamic Spectrum - Propagation Modelling / Clutter Attenuation

Tree clutter was causing dramatic attenuation in our ATDI planning software but in the field, trees were marginally affecting performance. We sought to apply an attenuation setting to the software to see if we could replicate the results we experienced in Cheshire and apply that to the other test results.

3. Dynamic Spectrum - Sustained NGA Performance

During our initial trials we found that TVWS devices could indeed achieve NGA compliance. We performed tests with Lancaster University and sought to understand if the results could be replicated over a sustained period.

3.3.3 Outcomes

1 Dynamic Spectrum - Antenna Array Improvements Findings

An opportunity to test a different antenna array came up in Arran. The 100-year-old chimney that the antenna array was attached to, began to show signs of wear and tear due in part to movement of the antenna in high winds.

In a consultation with the manufacturers, they concluded that the supplied antenna array is highly integral to the MIMO function of the radio and that significant power will be lost as a result of choosing a classic yagi antenna.

A new radio was set up and configured with two standard 75 Ohm Yagi antenna replicating the supplied panels set up directly in front of the existing client deployment.

The radio did not pick up any radio frequency from the base station on scan and was not able to establish a link.

Moving closer to the base radio showed no signs of improvement.

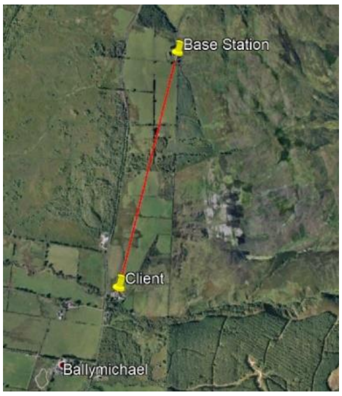


Figure 12

The radio frequency scan noise levels appeared lower than expected with the new antenna attached.

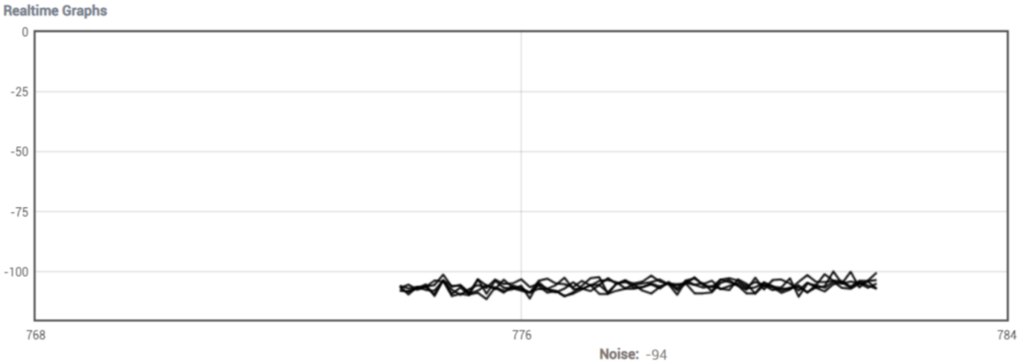


Figure 13

We concluded that the supplied antenna was integral as informed by the manufacturer, and that a significant amount more R&D is required to choose another antenna array to reduce wind loading and weight without hindering performance. Separate to the pilot this is under way with some sectorised-style panel antenna.

Whilst the size of the existing antenna array is a problem for wind loading in some areas, reducing the overall weight of the rig is possible by using lightweight aluminium instead of steel, for example.

We also concluded that the issues related to the chimney probably would have occurred with any 500 mm sized dish in that area but possibly not with a smaller Yagi.

2 Dynamic Spectrum - Propagation Modelling / Clutter Attenuation Findings

In the recommended Longley Rice model, clutter data was causing dramatic attenuation which did not match real world performance. The clutter imported into the planning tool was tree data.

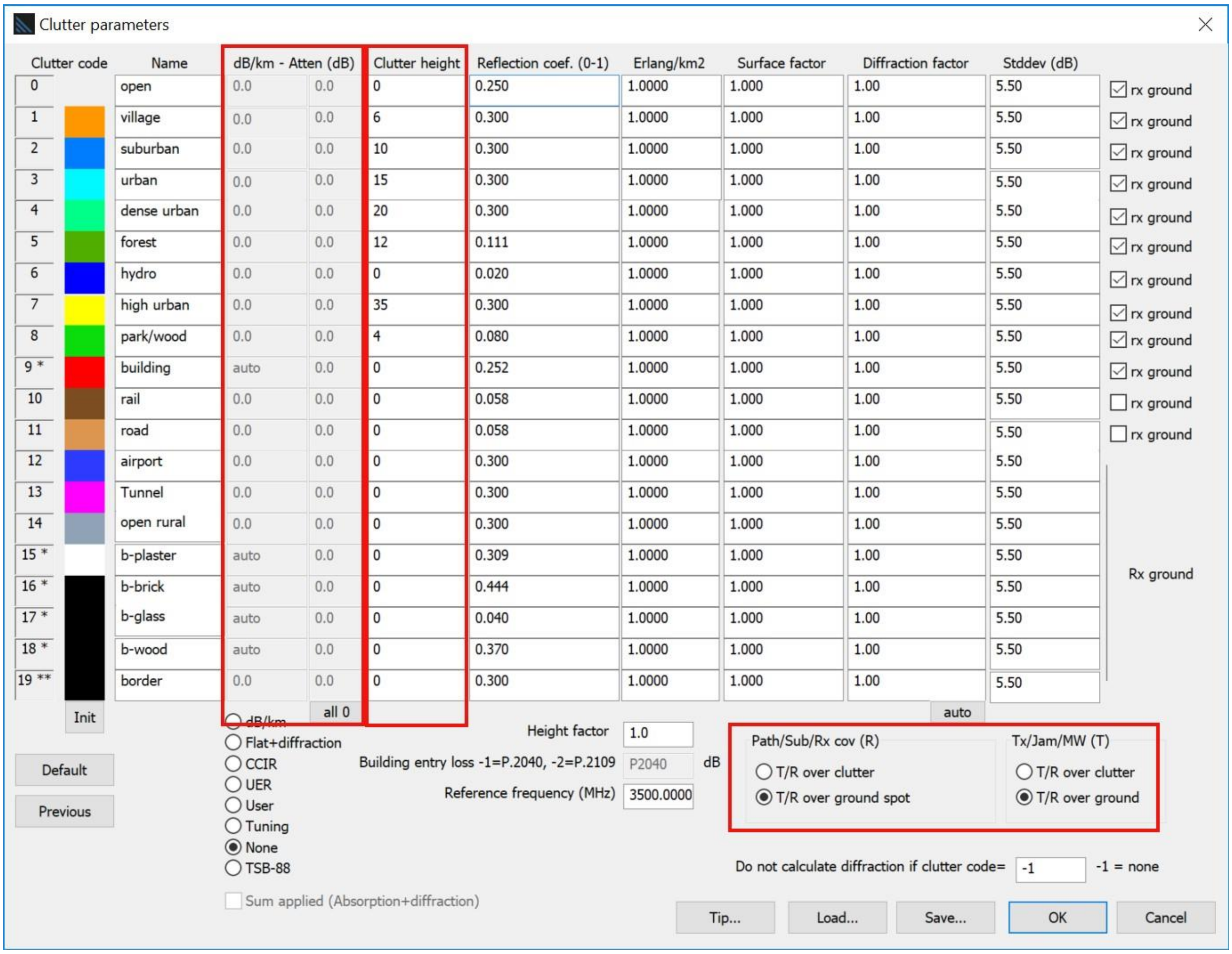


Figure 14

Using ATDI tools, it is possible to define the position of the transmitting and receiving (T/R) stations according to the clutter. Two options are available:

- T/R over clutter: in that case, the value set for the antenna height is defined over the clutter height.

- T/R over ground spot: the value set for the antenna height is defined over the ground.

For each clutter code (type of terrain), the user must set a specific clutter height. Two columns are available to define the attenuation applied to each clutter code.

The linear attenuation (first column) corresponds to the dB/km attenuation and the flat attenuation (second column) corresponds to a fixed attenuation added in different ways according to the mode selected. For each field strength calculation performed, two kinds of attenuations are computed: the diffraction and the absorption. Diffraction is a value calculated according to the propagation model and absorption corresponds to the clutter attenuation and depends on the selected mode.

3 Dynamic Spectrum - Sustained NGA Performance

Inverness

Inverness experienced sustained NGA performance over several months. Unfortunately, a large amount of speed test information to the local Lancaster speed test servers was lost due to a computer error.

Here is a small sample showing outstanding performance witnessed:

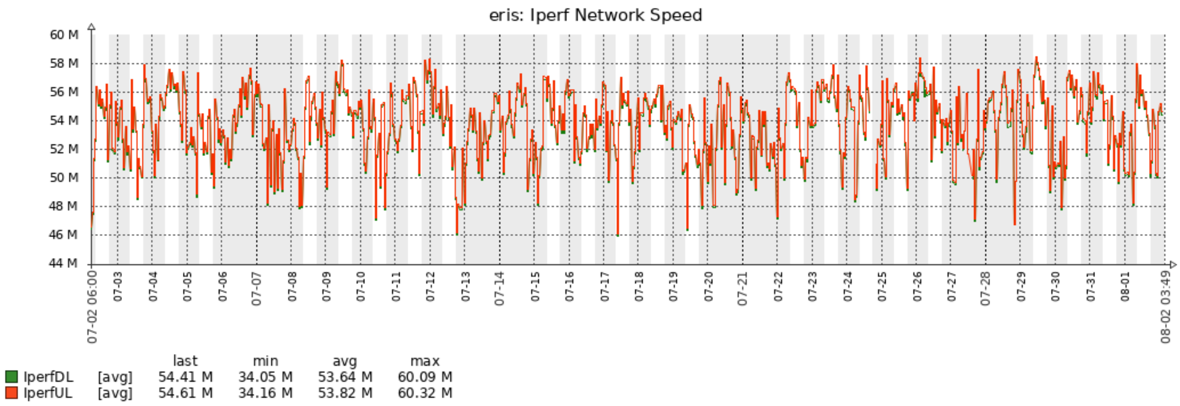


Figure 15

Thankfully speed test data was captured from Ookla speed tests servers. The Ookla speed tests server access was limited to a maximum of 30Mbps download and 5Mbps upload by the firewall at the edge of the network.

Taking into account TCP acknowledgement and the fact the speed tests servers are around 12 hops away from the network I estimate a 20% negative variance to the graph below based on a 30Mbps profile. If the speed was unrestricted speeds of 50Mbps are possible.

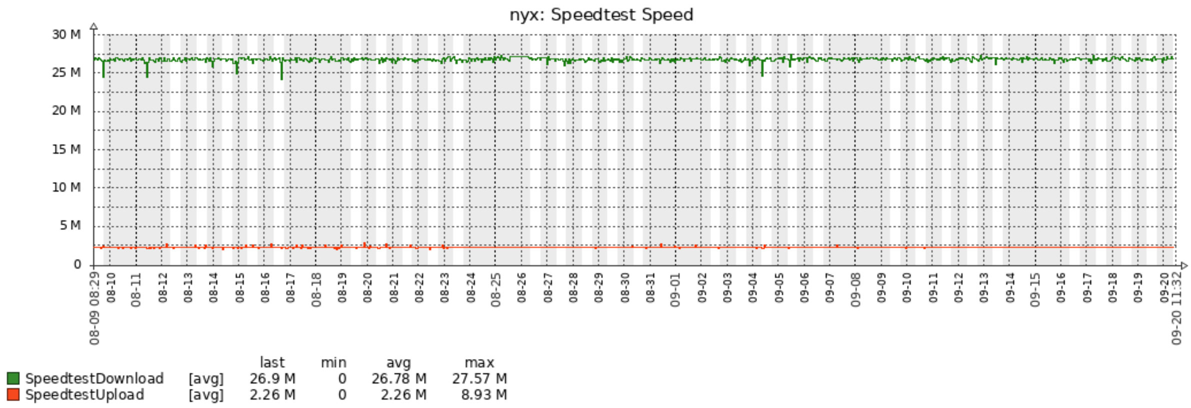


Figure 16

Kintyre

In Kintyre on the same profile the results were largely the same as Inverness.

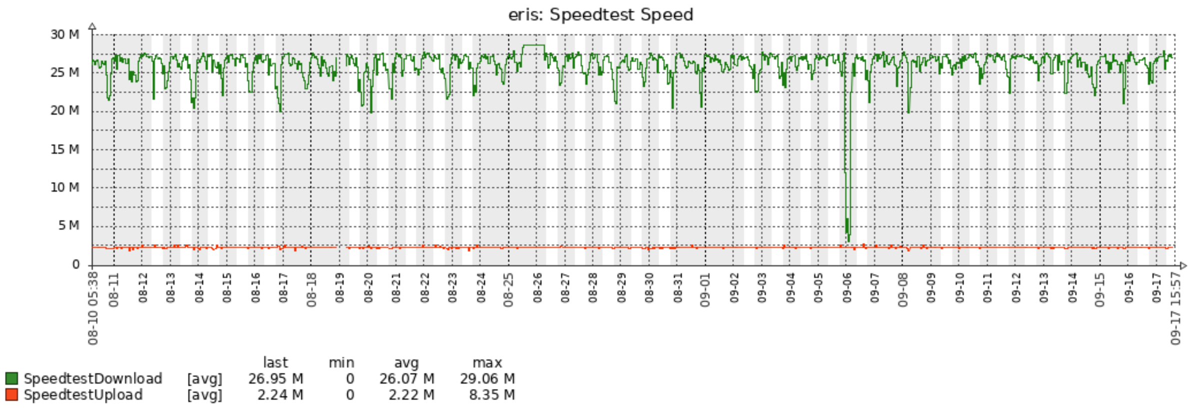


Figure 17

This sample proves that NGA compliant connectivity is entirely possible with TV White Space technology. The average speed considerably exceeds 15 Mbps 90% of the time with peak access speeds recorded in Inverness at 60.32Mbps – more than double NGA requirements.

3.1.1 Conclusions

Following extensive consultation with ATDI, we concluded that the sample size was too small to accurately assign a single value for attenuation with clutter for TVWS.

In the Cheshire Longley Rice model, the receive signal of the client seemed to experience little to no detectable attenuation effect.

We concluded that it was necessary to add a small amount of attenuation for short links in wooded areas, but further research is required to understand more about attenuation from clutter in this band.

3.2 QL - 60 GHz Equipment

3.2.1 Equipment

QL's experience with point to multi-point 60 GHz equipment is more positive than TVWS based on the following criteria:

- Successfully tested individual point to point links and single access points running a smaller number of connections
- Test multiple transmitters in a small geographical highly dense area all running simultaneously.
- Trial users have consistently reported high double / triple digit speeds tests as revealed through the implementation and milestone reporting.

The 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 and attenuation characteristics, most notably its water and oxygen absorption rates 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.

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.

5GRIT partners experienced great success using 60 GHz equipment in rural areas, however recognising its limited range, with customers were experiencing stable broadband connections >50Mbps.

3.2.2 Locations

The results from the trial locations during Phase 1 encouraged the development of the project for the Phase 2 network at Ingoldmells.

Location 1 - Auckley

The deployment of 60 Ghz equipment into the rural housing estate in Auckley, Doncaster, Figure has already been documented and continues to provide high double digit / low high triple digit throughput speeds in a dense environment.

The monitoring data supplied by LU showed that, despite the high density area for deployment, the technologies performed well with a consistently high throughput, and it has the ability to reach potential connections up to a 700 metre radius. 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. This made the work packet use cases fit the requirement and so provide an ideal test bed for the 60 GHz trial.

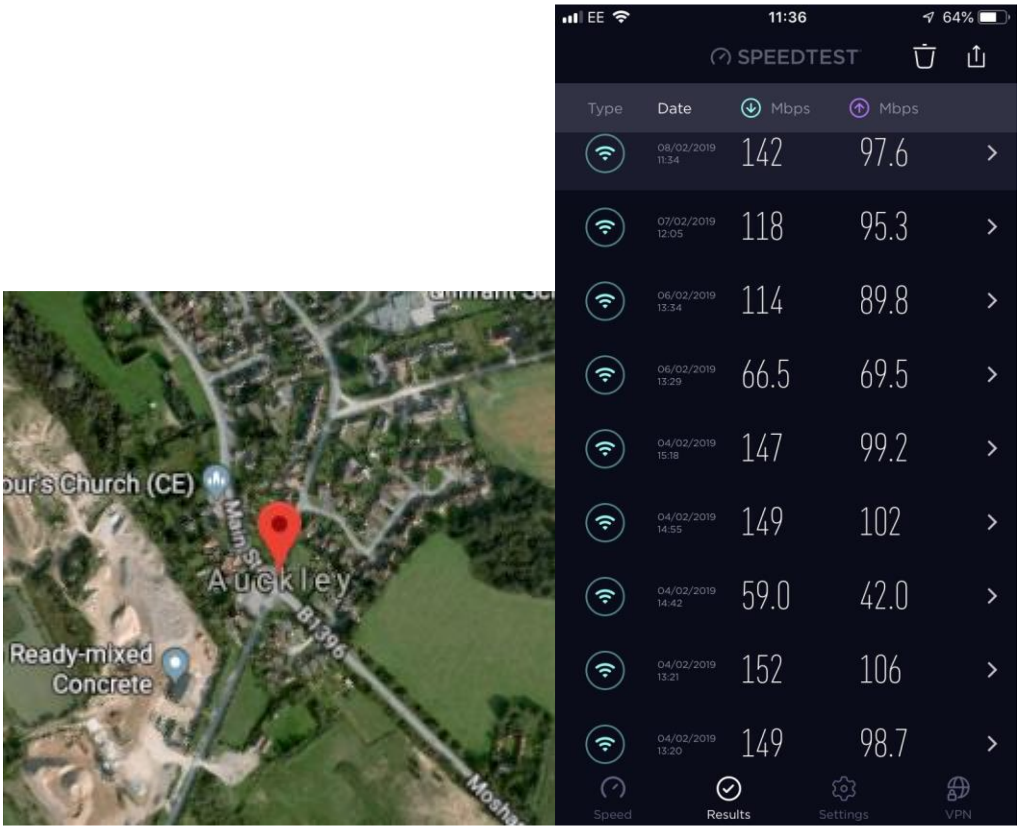


Figure 18

The graphs below Figure 19 and Figure 20 demonstrate that over a 2 month monitoring period, the service was able to provide an average throughput of 101 Mbit/s, far exceeding NGA requirements. Average latency statistics returned less than 15ms, which is excellent and less than most domestic VDSL installations.

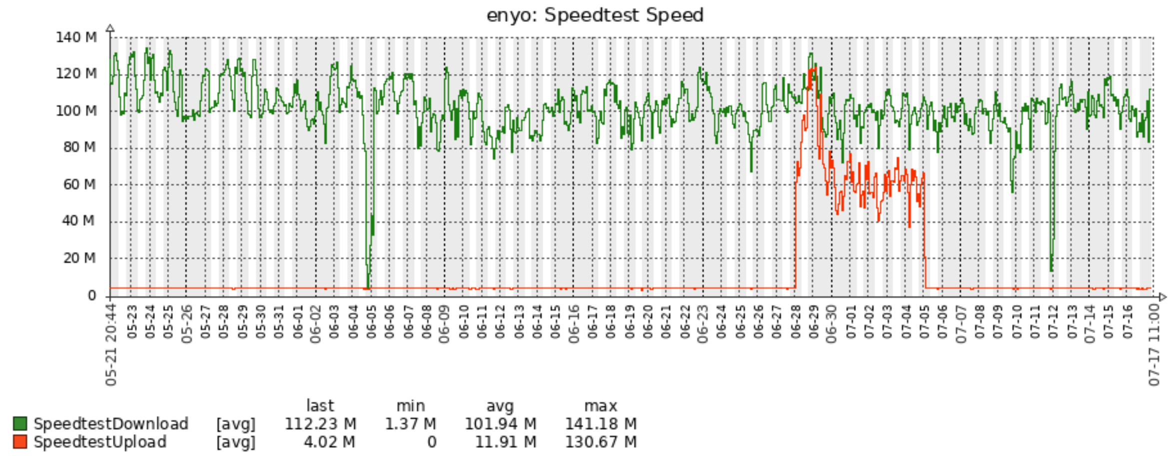


Figure 19

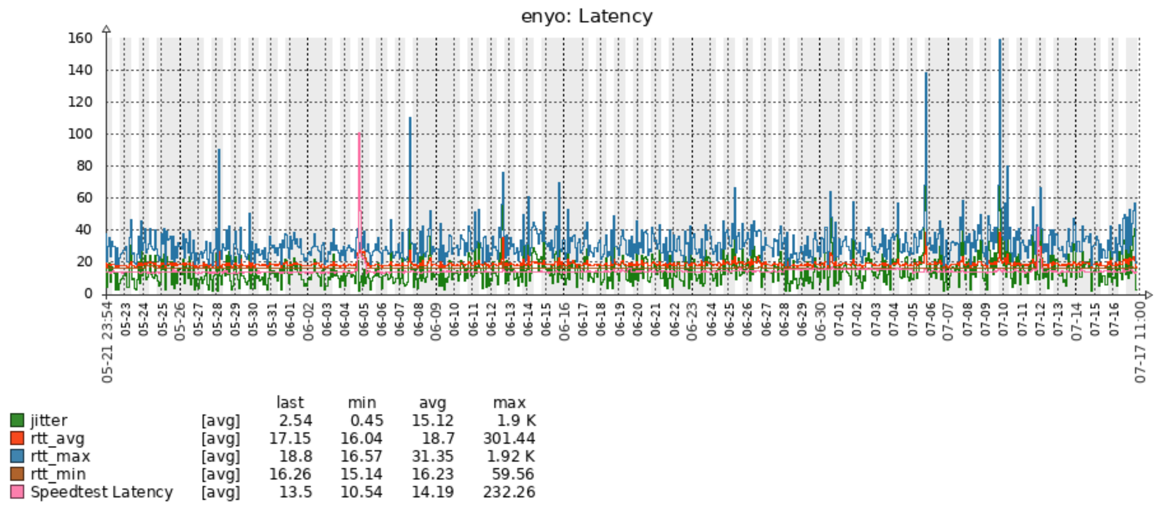


Figure 20

The use cases for deployment of 60 GHz technologies in Auckley, Doncaster, were geared supporting supporting the teleworker / home user use cases, given the demographic prevalent in the area. In this location 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 delivering superfast speeds.

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 **,** depicting misalignment. In this particular use case, the end users 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.

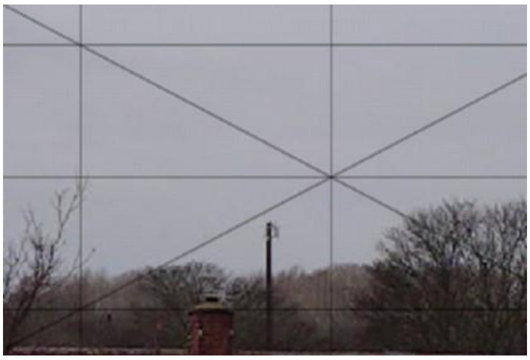


Figure 21a

Figure 21b

Figure 21

Figure 21a shows how, after a windstorm, the end user's client installation has become mis-aligned and as such, the user reported speed degradation.

Figure 21b 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 capabilities when under duress.

Summary

The purpose, identification and creation of a phase 1 60 GHz network was to facilitate the installation of selected technologies to be tested as part of this trial, understand the intricacies of installation given the relative lack of maturity of the technologies, the operational parameters and conditions of optimum runtime, and create a blueprint for future commercial and elevated roll out, 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 was 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 given the level of demand and changing use demographics, but also assist in answering the question: ***Can 5G deliver 30Mbps broadband compliant with BDUK's state aid requirements in rural areas at scale?***

The model for such would be to identify a limited concentration of potential end users, 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 end users providing feedback, speed tests and narrative throughout. This feedback is key to establishing inclusion at the completion of 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 end users point of installation. It is also important to recognise the importance and involvement of third parties to facilitate the phase 2 implementation, without which would not have progressed.

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

Location 2 – Ingoldmells

In Phase 2, Figure 22 of 60Ghz deployment, QL planned 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 into the thousands.

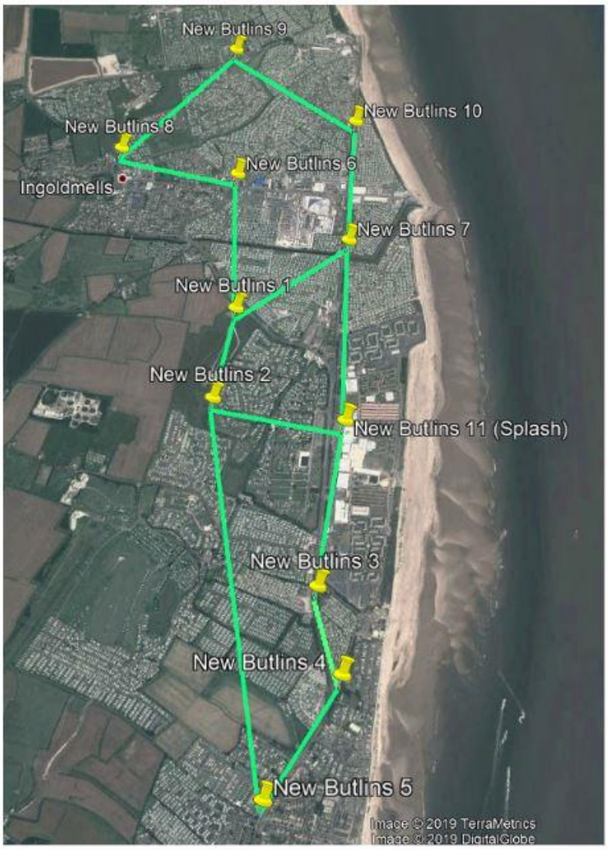


Figure 22

Advancing the findings from Phase 1 deployment of the Auckley 60 GHz Ignite equipment, in a densely populated area, the QL technical team has now completed the deployment of a solution which is anticipated to deliver a superfast infrastructure throughout a rural area, and potentially act as a blueprint for future plans elsewhere which perform a similar match both demographically and geographically.

Ingoldmells: Future plans - Commissioning & Connectivity:

QL has now reached the anticipated goals for MS8 & MS9; the final elements of phase 2 now completed the end user community throughout the area has started to be migrated across to the replacement 60 Ghz infrastructure with significant and positive feedback from an end user community, who previously had to settle for low, single digit connection speeds, see Figure which depicts the mast infrastructure and end user community in the distance. Much as in keeping with the results of the speed tests obtained in location 1 Auckley, customers are experiencing dedicated >30 Mbps superfast connectivity and so the solution, while in its infancy, is matching the demand for the changing demographics of use and answering the question posed by DCMS. Consumers while on holiday are choosing to take from their primary residence to a holiday home, the technology comforts such as games machines, streaming services, and multiple wireless hardware devices which has created the augmented demand in the first place but outstripped the historical technology deployment.

Figure 23

3.2.3 Key learnings & conclusions for 60 GHz trial locations

Conclusions while positive and encouraging have provided the following:

Technology Readiness Levels [TRLs]

- The choice of 60 GHz supplier had a positive impact on the project's deliverables from a QL perspective. Given the 60 GHz TRL, by comparison to commercially established equipment, QL was able to procure and deploy quickly, then harvest positive results from phase 1 trials.
- QL was able to work closely with the manufacturer and identify bug fixes and implement replacement firmware to alleviate, and maintain project momentum.

Alignment

- With any line of sight [LoS] technology, 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 attenuation.

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 60 GHz 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 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.

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 attended public meetings with a view to responding to questions submitted from the public to appease any anxieties raised from challenging sources.

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 infill 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.

- ***Can 5G deliver 30Mbps broadband compliant with BDUK's state aid requirements in rural areas at scale?*** In regard to 60 GHz it could be summarised from evidence gathered throughout this trial, and so suggested that it very much has a role to play if considered for extended use in a large scale deployment. Based on what we have learned from the phase 1 trial using point to point and point to multi point connections, it can be upscaled to deployments which take into account large and densely populated areas in rural communities hitherto untouched by fibre provisioning, provided the initial backhaul is present to supply the main connectivity into the mesh infrastructure. Successful connectivity is clearly attainable, measurable and reportable, without any significant adverse consideration towards consistency and reliability [as with TVWS], and so given the right infrastructure deployment could be considered as a mass rollout technology to attain a move towards a 100% connected Britain using 60 Ghz.

3.3 BP – 60 GHz Equipment

3.3.1 Gigabit - 60GHz Mesh in Rural Monmouthshire

Network Layout

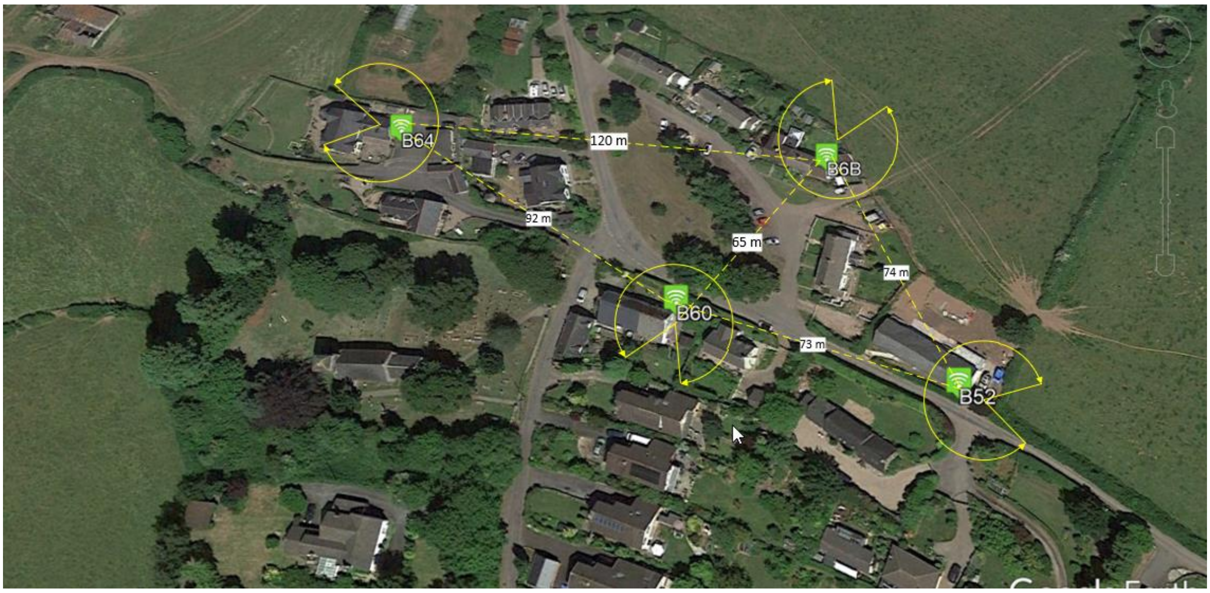


Figure 24

3.3.2 Test Design

The Gigabit backhaul network in Monmouthshire has several commercial customers connected on a variety of packages from 30-100M bps.

At busy times from the village hall site at B52 we can regularly hit very high speeds to Ookla test servers on an unrestricted account.

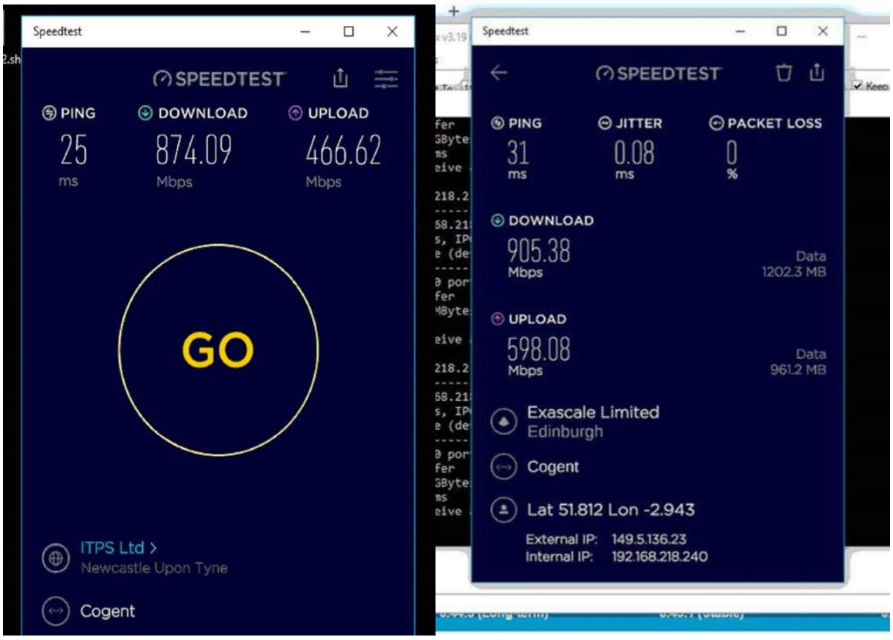


Figure 25

3.3.3 Test Issues

Capturing information from the Lancaster University test servers did not initially go as planned. Despite the device being accessible externally and able to connect to the internet, the device could not connect to the test server. When we managed to get the test devices working, all the devices started to disconnect during the test. This was because all of the devices were performing the test concurrently and the server was timing out. Once the tests were sequentially timed, it was found that the test device could not achieve high speeds when compared to the manual iPerf and "switch to switch" tests we produced during implementation of the mesh.

With further tweaking the device started to work and we managed to capture a good amount of iPerf data as well as user test data.

3.3.4 Ethernet Throughput

Baseline

From PC to PC, directly connected over a 3 metre ethernet cable, with nothing else connected to the network, a short iPerf test produced a baseline average throughput of 970 Mbps UDP utilising the same 5 port Gigabit switch as the pilot.

It can therefore be assumed that anything close to 970 Mbps is the maximum capability of a PC connected to a switch over ethernet in lab conditions.

Network Configuration

The radio network consisted of four nodes each connected to a small 5-port Gigabit switch. When we designed the test, we did not think that a 10Gbps fibre interface between the switch and the radio would be necessary due to the constraints of the Lancaster test PCs which feature a copper based 10/100/1000 Mbps capable NIC. We also did not know for certain if we would achieve the maximum throughput capability of the PC in the pilot.

Having conducted the test, we feel the fibre connection would have enabled even faster speeds over the mesh.

The radio and switch inside the radio, according to lab results are more than capable of providing higher speeds.

Due to the connection being split between users and test equipment we found some network contention which occasionally interfered with the radio tests results of the automated test servers, especially if coincidentally a test user ran a speed test at the same time as the test PC ran its tests.

3.3.5 Logical Network Layout

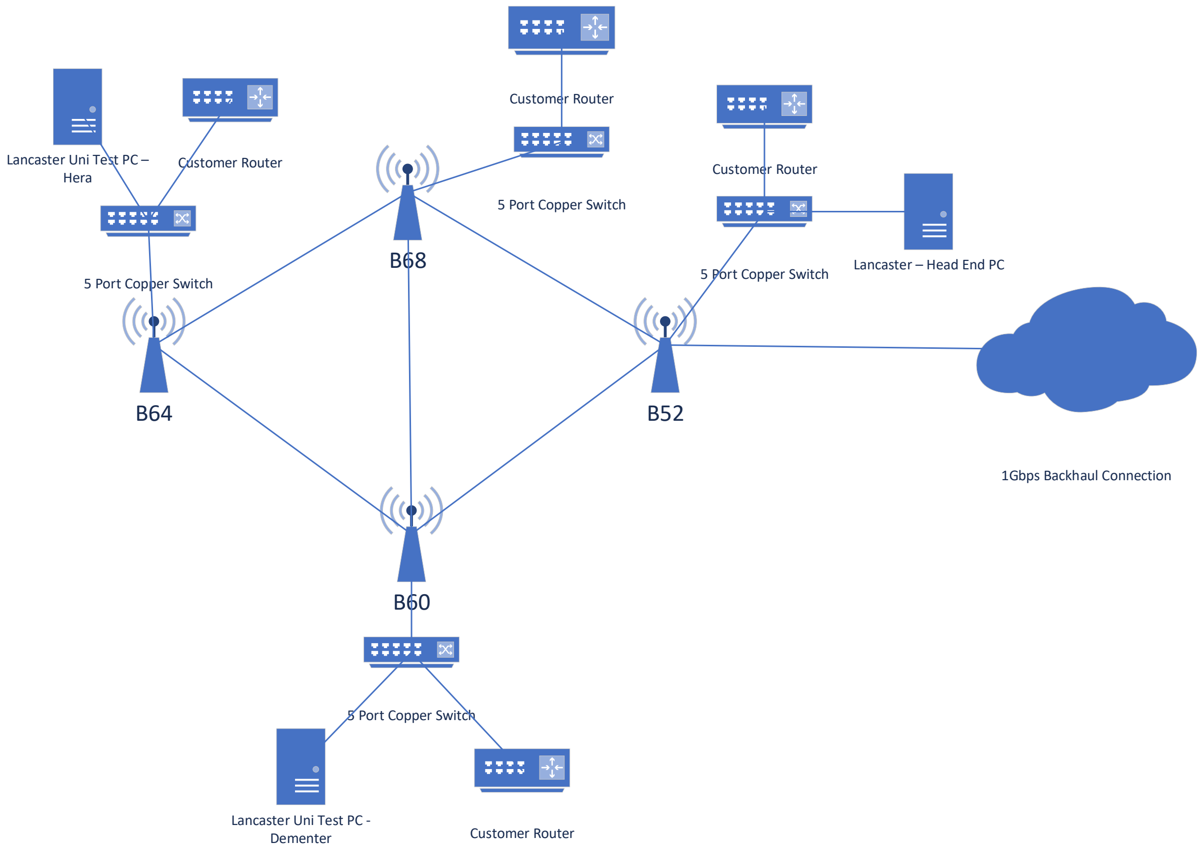


Figure 26

3.3.6 Wired Continuous Speed Test Results

The test results were recorded from 15/08/2019 at 8:00am to 19/08/2019 at 4:00pm.

B60 Test Results

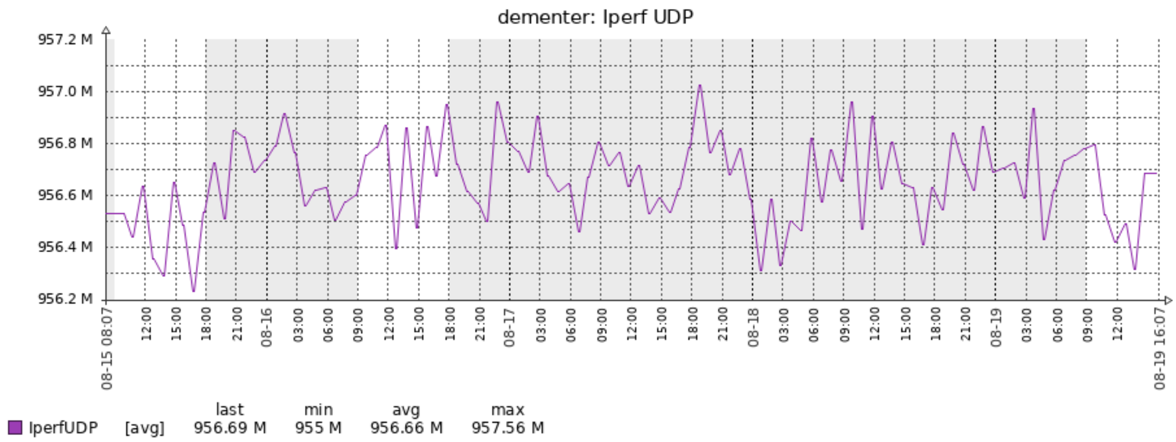


Figure 27

B64 Test Results

The test results were recorded from 15/08/2019 at 10:30am to 19/08/2019 at 4:00pm.

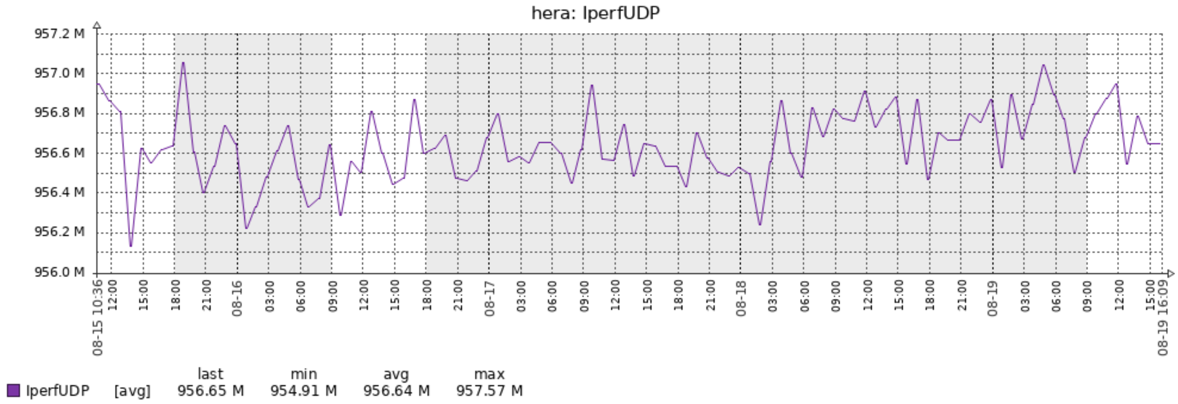


Figure 28

The results show that over the sustained and intensive test period, the speeds were very close to Ethernet throughput in lab conditions.

Impressively, the mesh switching capability of the middle node, B60, did not appear to cause any overhead at all to throughput, strangely averaging almost exactly the same as the first node in the mesh, B60.

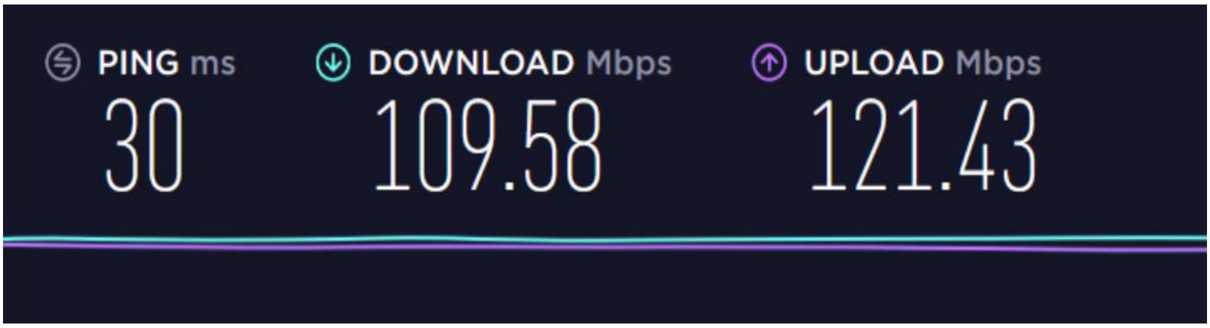
3.3.7 User WiFi download speeds (Ookla)

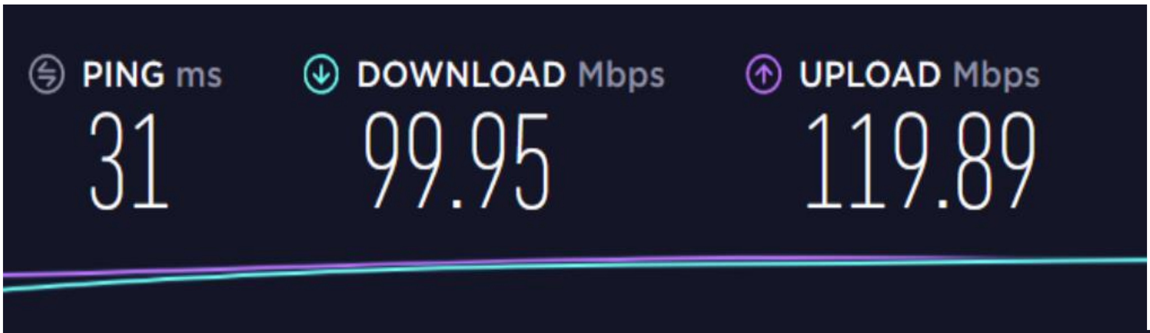
The problem with providing a 1 Gbps connection is that in order to fully experience the connection benefits, you have to have a device capable to utilising the bandwidth.

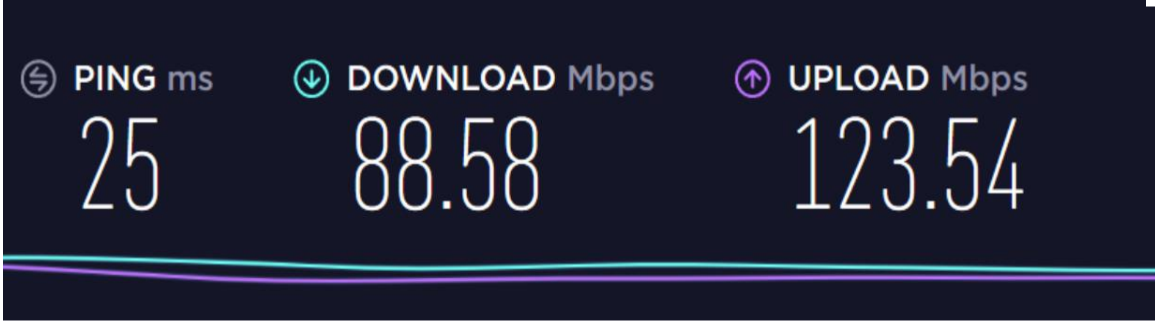
Whilst we proved that the users benefited from 1Gbps connectivity using the test PCs directly connected to the radio, we overlooked the capability of the devices utilised by the end users.

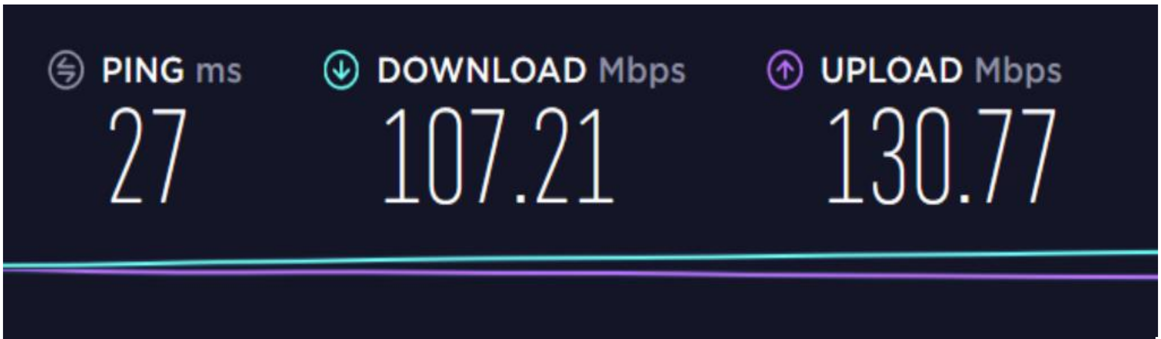
In addition, some of the properties were quite large, so WiFi signal around the properties was hindered. The WiFi connection that users seemed to default to was a 20Mhz 2.4GHz channel, rather than the faster but less "punchy" 5Ghz channel.

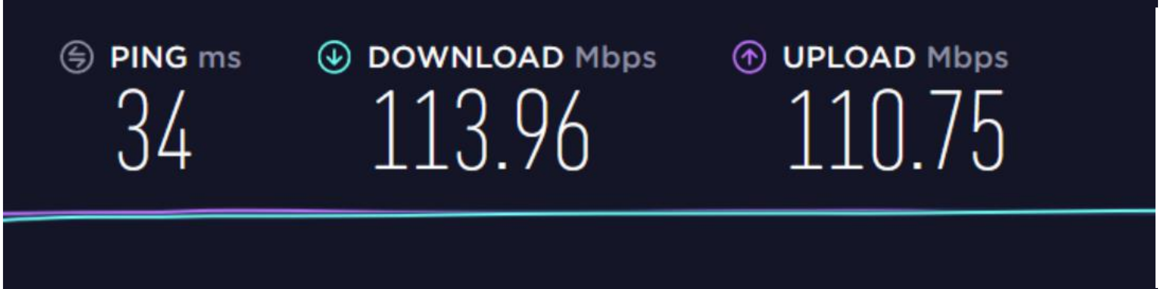
Therefore, we estimated the highest achievable speed for most user devices was 150Mbps with a good quality WiFi connection and wholly dependent on the location of their device.

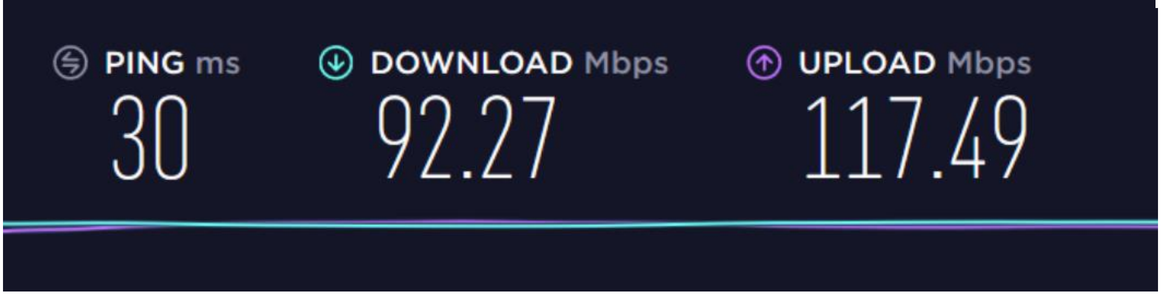


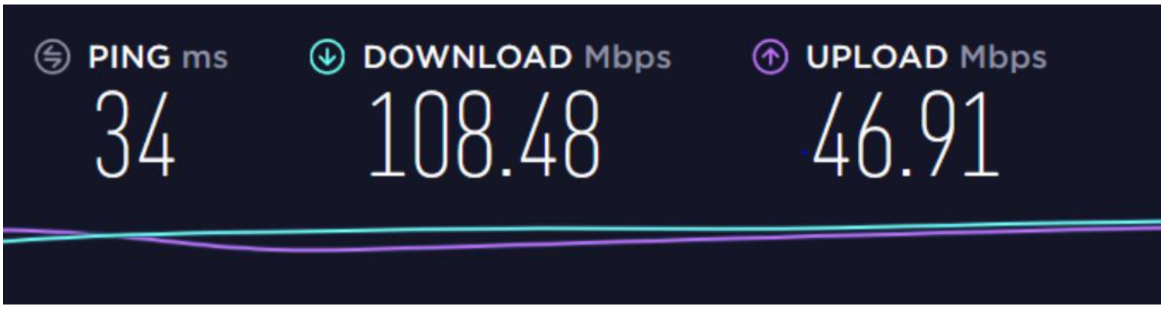

PING ms
31
DOWNLOAD Mbps
99.95
UPLOAD Mbps
119.89


PING ms
25
DOWNLOAD Mbps
88.58
UPLOAD Mbps
123.54


PING ms
27
DOWNLOAD Mbps
107.21
UPLOAD Mbps
130.77


PING ms
34
DOWNLOAD Mbps
113.96
UPLOAD Mbps
110.75


PING ms
30
DOWNLOAD Mbps
92.27
UPLOAD Mbps
117.49


PING ms
34
DOWNLOAD Mbps
108.48
UPLOAD Mbps
46.91

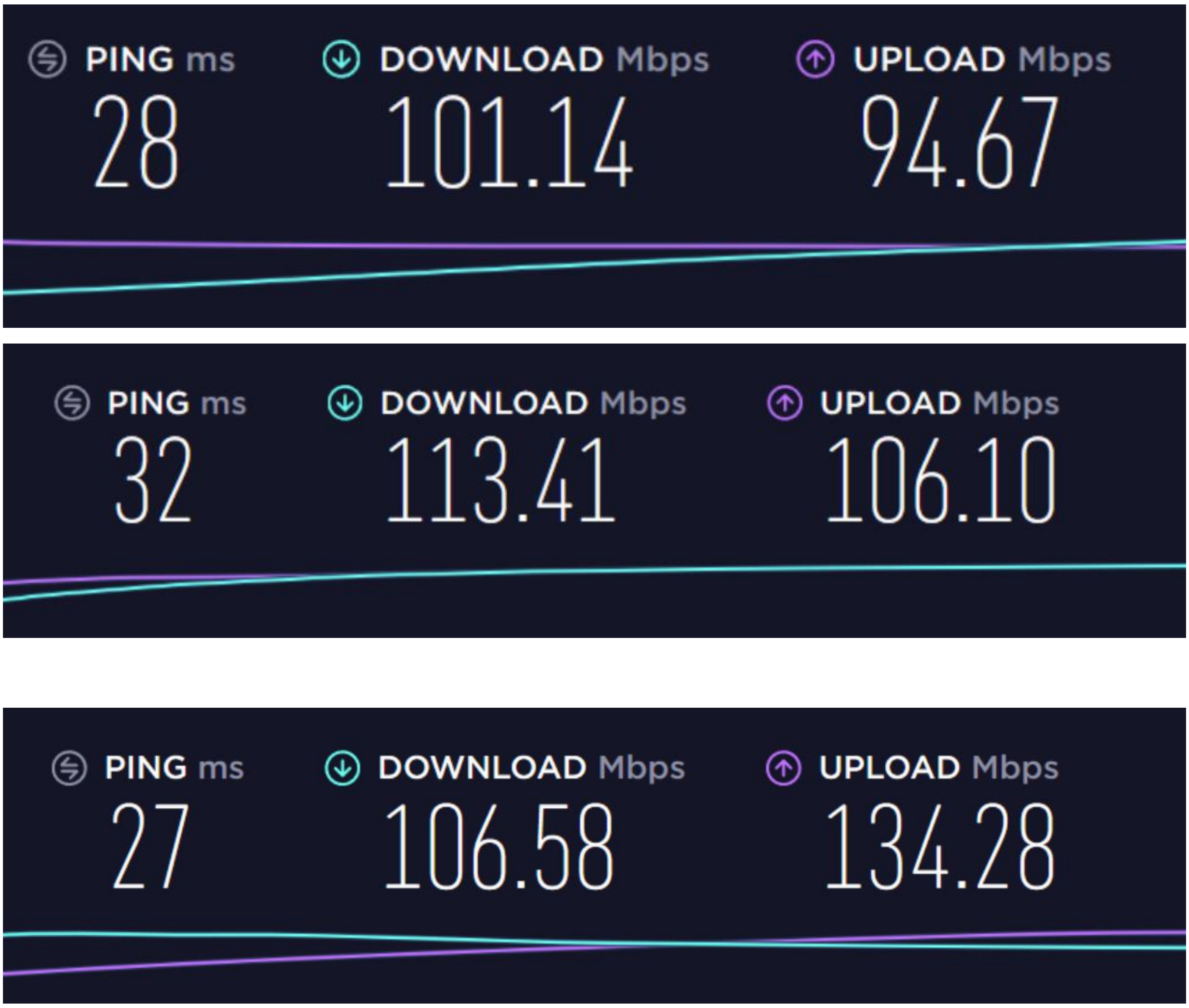


Figure 29

3.3.8 Conclusion

The mesh radio network easily coped with Gigabit throughput, even through the mesh node. It would have been more interesting in hindsight to have equipped the radios with a fibre interface to attempt to “max out” the radios.

From a user perspective considering subscribing to a Gigabit service, the additional speed has to be utilisable by the user devices. If the best signal a device can achieve combined with the age of the wireless adapter is 140Mbps, that is the maximum utilisable speed for all devices on that wireless network.

Excluding the speed test data, the average peak download speed of a user was as little as 1.2 Mbps.

This indicates that whilst Gigabit speeds are impressive technically and more than capable of being delivered, there is a way to go before the pilot users will require this sort of speed.

4 OVERALL CONCLUSION

Can 5G deliver 30Mbps broadband compliant with BDUK's state aid requirements in rural areas at scale?

The findings and therefore conclusions revealed from phase 1 differ between technology choice 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 regard to Longhills, Lincolnshire, deployed to support the rural community 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 introduced, 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 elevation 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.

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?

We would suggest that 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. 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, the last 10%, can be achieved with pure fibre but it can be in conjunction and faster with a mix of fibre and radio.

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