REPORT ON SCOTGOV STUFF

PETER BUNEMAN AND WILLIAM WAITES

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1. Summary

The Demonstrating Digital Programme of Scottish Government provided a small grant to the University of Edinburgh to test wireless equipment that may be useful in the deployment of rural community broadband. Although most community networks are currently limited not by the speed of their wireless links, but by the available bandwidth, it is to be hoped that this will be improved with the current....

A manufacturer of low-cost wireless distribution hardware has recently released some low cost equipment operating in the 24GHz and 5GHz spectrum. If it lives up to its specifications, it offers an order of magnitude increase in the capacity of current point-to-point links over existing technology that operates in the spectra that are available to com munites. In addition we tested laser (free-space optics) equipment operating in an urban environment but also serving rural communities.

To summarise our findings.

- The 24 GHz equipment could prove useful over relatively short distances (up to 8 km) if licencing permitted use at the power for which it is designed.
- Given the current power limits and available bands in the 5GHz range, the 5GHz equipment probably provides only a minor improvement on what could be achieved by using two or three parallel links using lower cost equipment in different bands. There is, of course, a simplicity/redundancy trade-off.
- The free-space optics equipment performs, as expected, well over distances of a few hundred metres, but will not be useful for longer links in a rural (Scottish) environment

The main obstacle to using the 5 and 24 GHz equipment is licencing. Under current regulations the 24GHz cannot be used, and the 5GHz equipment would be much more useful if (a) the power limits were to be raised and (b) Ofcom were to publish their database of licences in the C band.

2. Introduction

Many community broadband projects require a long-range wireless link for their connection to the Internet. The equipment of choice is currently based on wifi operating in the unlicensed 2.4 or 5GHz spectra. This is cheap: the equipment for a long-distance point-to-point link costs under £400 and can provide bi-directional throughput of about 50Mb/s. While this provides an improvement for the many rural communities that are served by long copper telephone lines, 50Mb/s is no longer adequate for a community of, say, 50 residences. Technically, there is no problem in getting more bandwidth in one of the licenced spectra, but the equipment is more expensive and the additional cost of the licence makes this option unaffordable for small communities.

Recently some new equipment operating at 24GHz has come on the market from Ubiquiti[1]. This is advertised as offering 1.4Gb/s at up to 13km. Although not as cheap (a point-to-point link costs about £3,000) it might present an opportunity for some rural communities to upgrade their service to be competitive with the current fibre based offerings in the UK, assuming they can find an internet connection with that bandwidth. A 5GHz variant is also produced by Ubiquiti claiming comparable speeds at upwards of 50km.

With this in mind, the Scottish Government's Demonstrating Digital programme provided the University of Edinburgh with funds to test this equipment "in the wild". Of course, there is ample evidence that the equipment works, but most of the evidence we have is from installations in urban areas over short distances. How will it perform over longer distances in West Highland weather? And what are the practical problems faced by communities who want to install it?

At the request of the Scottish Government we also evaluated an unrelated technology for use in urban areas – free-space optics. This means signalling by laser through the air instead of through fibre-optic cabling. The main question here was, since these devices operate in the visible spectrum, how well do they operate in reduced visibility conditions? Do they operate *well enough* for use in this climate over short distances. Again it is a question of cost. The equipment is expensive (some £8-15k per link) and requires careful mounting and alignment, but compared to the civil engineering cost of running fibre in urban areas, or leasing it, it may be worth it.

3. 24GHz experiments

3.1. **Background.** Before going into an account of the the project, let us look at some of the pros and cons of using this equipment and what is already known about wireless transmission in the 24 GHz spectrum. We have already noted that the equipment is affordable. The advertised throughput of 1.4Gb/s presumably means 700Mb/s in each direction, but that would provide a satisfactory connection for a hundred or so residences. Moreover, transmission in this frequency is much less likely to be affected by tidal reflection (a significant problem in the Highlands and Islands)

There are some significant drawbacks, though.

- In the UK, the 24.050–24.350GHz band is partitioned into three sub-bands[2], and these devices can use two of them. Of these two, one is reserved for government and amateur radio use and is not allowed for general use and the last is permitted at extremely low power densities (1.5 $\mathrm{mW/m^2}$ as opposed to the although the 13 $\mathrm{W/m^2}$ supported by the equipment. We obtained a "non-operational" licence from Ofcom in order to test the equipment at the advertised power and in both sub-bands.
- Several of the links used by Tegola and related projects are longer than 13km

[1] http://www.ubnt.com/airfiber

[2] Ofcom UK Bandplan

- Transmission in higher frequencies is adversely affected by high humidity and high temperatures. Scotland benefits from only one of these.
- The Ubiquiti equipment uses substantially more power than their 5GHz offerings – about 40W. This would make it unsuitable for solar and wind-powered relays.

Our initial plan was to test the equipment on existing Tegola relays one is a 6.5km link; the second 15.5km. Although the latter is over the advertised range, even a substantial fraction of the advertised throughput would be useful.

The following is a roughly chronological account of the project. The initial installation was done during a period of very high winds in early January 2014.

3.2. **Power output calculations.** Expanding on the first bullet point above, Ofcom has this to say about the part of the 24GHz radio spectrum used by this equipment in the UK Bandplan[3]:

> *Non-government low power devices in the radiolocation services are limited to:*
>
> *(a) Portable and fixed applications between 24.15-24.25 GHz; and*
> *(b) Mobile applications between 24.25-24.35 GHz on a NIB to the radionavigation service*
>
> *Power flux-density at 10 metres from the system antenna in the direction of maximum radiation is not to exceed* $1.5\,mW/m^2$ *without approval*
>
> *24.05-24.25 GHz is used by the Amateur service. The part of the allocation between 24.05 and 24.150 GHz may only be used with written consent of the Secretary of State.*
>
> *Home Office/Office of The Scottish Executive for the Emergency Services between 24.05-24.15 GHz*
>
> *ISM apparatus may use the band 24.0-24.25 GHz.*

Also, the UK Spectrum Strategy 2000 (appendix B)[4] allows this frequency range to be used for “Technology Development” for low-power fixed and portable devices. In this context, “low-power” means less than $1.5\,\mathrm{mW/m^2}$.

The regulations are confusingly laid out, it would appear from the arrangement of the text that the sentence “The part of the allocation between 24.05 and 24.15 GHz may only be used. . . ” pertains only to the amateur service, but it seems to be a global restriction, particularly since another Ofcom document on Vehicle Mounted Radar Detectors[5] mentions that the police use this part of the band for radar speed meters.

So generally it is allowed to use this equipment in the UK, it is just necessary to check the output power and keep away from the bottom half of the band. The airFibre datasheet[6] gives dBm and the government, gives the permitted radiation energy per unit area at 10 meters from the system. So we need to do a bit of arithmetic.

The datasheet says that the beam-width is less than 3.5°. Let’s make a simplifying assumption that it is exactly that width and further that the cross-section of the main lobe

[3] http://www.ofcom.org.uk/static/archive/ra/publication/ra_info/ra365.htm
[4] http://www.ofcom.org.uk/static/archive/ra/topirum-strat/future/strat00/appendixb.pdf
[5] http://www.ofcom.org.uk/static/archive/ra/topics/research/rtcg/projects/project706.pdf
[6] http://www.ubnt.com/downloads/datasheets/airfiber/airFiber_DS.pdf

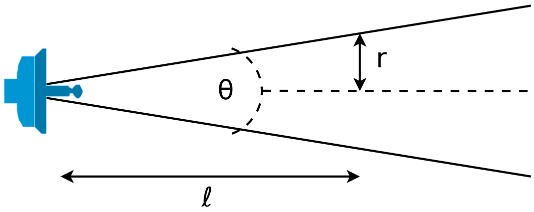

FIGURE 1. Directional radiation cone

of radiation is circular as depiceted in figure 1. The radius of the cross-section will be,

$$r = \ell \sin\left(\frac{\theta}{2}\right) = 10\,\mathrm{m} \times \sin\left(1.75^\circ\right) = 0.m\,\mathrm{m} \tag{1}$$

The area of this circle is, $\pi r^2 = 0.3\mathrm{m}^2$.

So now, how much power goes through one square meter when transmitting at 33 dBm?

$$p = \frac{10^{\frac{1}{10}\beta}}{a} = \frac{10^{\frac{33}{10}\,\mathrm{dBm}}}{0.3\,\mathrm{m}^2} = \frac{1995\,\mathrm{mW}}{0.3\,\mathrm{m}^2} = 6.7\,\mathrm{W}/\mathrm{m}^2 \tag{2}$$

Clearly this is well in excess of the permitted output power.

3.3. **Link budgets.** This experiment is meant to compare the real world performance against the vendor's claims, but first let us see how the claims stack up against the theoretical performance. To get an upper bound on possible throughput we use the Friis Transmission Equation,

$$P_r = P_t + G_t + G_r + 20\log\left(\frac{\lambda}{4\pi d}\right) \tag{3}$$

where P_t and P_r are the transmitted and received power levels, G_t and G_r are the gains of the antennae at either end and the last term describes the path loss due to distance and wavelength. This is an ideal model and doesn't account for other real-world sources of loss.

We will consider two cases, the usual legal limit and the 33 dBm transmit power. We know the legal limit is $1.5\,\mathrm{mW}/\mathrm{m}^2$ so again we need to do some arithmetic using equation 2 in the reverse direction,

$$\frac{10^{\frac{1}{10}\beta}}{0.3\,\mathrm{m}^2} = 1.5\,\mathrm{mW}/\mathrm{m}^2 \tag{4}$$

which we can re-arrange and solve for $P_t + G_t = \beta = -3.5\,\mathrm{dBm}$.

To make use of equation 3 we need some more information. To find the wavelength, we use,

$$\lambda = \frac{c}{f} = \frac{299,792,458\,\mathrm{m/s}}{24\times 10^9\,\mathrm{Hz}} = 0.0125\,\mathrm{m} \tag{5}$$

where c is the speed of light. We also look up in the datasheet and see that the receive gain, G_r is 23 dB.

So as a first calculation, let us see what receive power can be expected at 13 km,

$$\begin{aligned} P_r &= -3.5\,\mathrm{dBm} + 23\,\mathrm{dB} + 20\log\left(\tfrac{0.0125\,\mathrm{m}}{4\pi\times 13{,}000\,\mathrm{m}}\right) \\ &= -3.5 + 23 - 142 = -122\,\mathrm{dBm} \end{aligned}$$

Referring again to the data sheet, we find that the weakest signal that can sustain a connection (at about 3 Mbps since we would need to use 10 MHz wide channels – the datasheet is misleading on this point since it only quotes throughput numbers for 50 MHz wide channels) is −95 dBm. At the legal limit we are 27 dB or about 500 times weaker than we need to be to sustain a link at the advertised distance. Clearly transmitting at 33 dBm with our non-operational licence this is feasible, indeed we have 12 dB margin to spare which, again referring to the datasheet, should net us 128 Mbps over this distance.

So let us ask another question. Over what distance is it possible to sustain the maximum advertised throughput? For this, according to the datasheet, we need a receive power of at least $P_r = -58$ dBm. Solving equation 3 for the distance, d, we get,

$$d = \frac{\lambda}{4\pi} 10^{\frac{1}{20}(-P_r + P_t + G_r + G_t)} \tag{6}$$

which works out to all of 7.5 m at the regulatory limit and 500 m at 33 dBm.

In our case we are planning to run this on links at most 6 km where the same calculations say that we can expect a receive signal level of around -79 dBm which means that using 40 MHz wide channels we should be able to solidly sustain links at 256 Mbps or better for shorter links.

3.4. **Initial configuration and testing.** We ordered and received one pair of radios. Before deploying them we thought it would be a good idea to check that they were working and test them in ideal situation – our office corridor. One thing we immediately noticed was how critical alignment is. Even over a distance of 35m, the performance fell of dramatically if the antennae were slightly out of alignment. It's a very good idea to configure equipment before deploying it, but to do this we had to turn off sychronisation which relies on GPS and doesn't work indoors.

3.5. **Strengthening the masts.** Our basic relay construction (see the relevant howto on the Tegola web site) uses aluminium pegs to anchor the diagonal braces to the ground. Both sites were on terrain that consisted of bedrock covered by peat of varying depth. Although we have never had a problem with the pegs shifting, peat is a bit jelly-like, and the structures can wobble through a cm or two. The alignment of 24GHz is much more critical than for the lower bandwidths of 2.4 and 5.8GHz, so we replaced the pegs with epoxy bolts into the bedrock.

FIGURE 2. Pegged anchors (left) and epoxied anchors (right).

We also strengthened both relays. For example, at one of our relays we added an extra horizontal bar.

FIGURE 3. Corran mast before (left) and after (right)

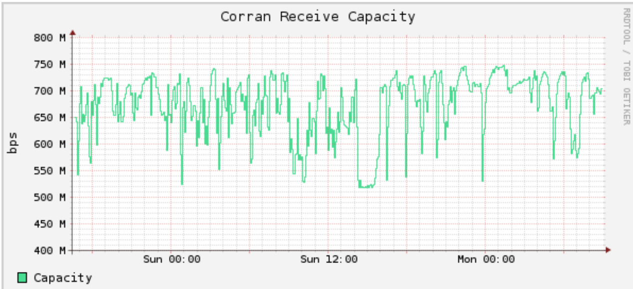

FIGURE 4. Corran receive capacity...

3.6. **Installation and alignment.** The radios are reasonably light (under 10kg) but awkward to carry up hills. We used an old backpack frame that 30 years ago had been used for carrying batteries up to community TV relays. The radios come with a mounting frame that is first attached to the structure. The radio is then "slotted" into the mounting frame. This arrangement makes it quite easy to install the whole assembly when working from a ladder.

The antenna can be aligned through elevation and azimuth adjustment screws. Unfortunately there is a great deal of backlash in these screws, and they are almost useless if you are working in high winds. If the clamping bolts are loose, the antenna is blown around through the considerable travel allowed by the adjustment screws. The signal strength read-out is at the bottom of the antenna, and if the alignment is being done from a ladder, you almost certainly need someone below (with a hard hat) to squint up and call out the figures.

The installation instructions recommend an alternating process in which one end of the link is adjusted then the other, and so on. Unfortunately we were unable to complete this process before the weather closed in and our workforce departed. However, the alignment is good enough that we can start taking some measurements. The initial indications are that the link will work reasonably well over a distance of 6.5km.

3.7. **Performance.**