Deployment of wireless home networks in the UHF broadcast spectrum

(Project No: BV371N)

Technology Strategy Board
Digital Britain Feasibility Study

Final Report

2204/AHN/FR/1

24th February 2010

ÆGIS spectrum engineering

Table of Contents

1 INTRODUCTION

Wireless networks are extensively deployed in the home using the 802.11 family of standards commonly referred to as "Wi-Fi" and currently operating in the 2.4 GHz and 5 GHz bands. Wi-Fi plays an important role in facilitating broadband access but performance can be patchy in larger homes. Access to a lower frequency range may help in this regard and also facilitate provision of community Wi-Fi networks as an alternative mobile broadband platform. One approach might be to deploy wireless networks within the UHF TV broadcast band (470 – 790 MHz), using "white spaces", i.e. frequencies that are not used by local TV transmitters or other licensed users.

This study addresses five key issues in relation to the potential deployment of UHF TV band frequencies for wireless home networking, namely:

i) The current status of white space technologies that might be suitable for home network deployment in UHF white spaces

ii) The improvement in coverage quality that might be achieved using white space frequencies in a typical residential environment

iii) The potential availability of white space frequencies in the UK

iv) The potential for interference between wireless home networks and other devices in the home and

v) Any regulatory implications of using white spaces in this way.

The findings of our study with regard to each of these five issues is summarised in the following sections.

2 CURRENT STATUS OF "WHITE SPACE" TECHNOLOGIES AND THEIR APPLICABILITY TO HOME NETWORKING

2.1 Introduction

"White space" frequencies first attracted interest in the US as a means of providing cost effective wireless access in rural areas. The relatively sparse use of VHF frequencies in the USA makes deployment of such wide area networks particularly attractive. In the UK the UHF frequencies are used much more intensively for TV transmission (see map below) and white spaces may therefore be better suited to lower power applications comparable to today's Wi-Fi systems. This would require access to the frequencies on a licence-exempt basis, consistent with the existing Wi-Fi bands.

Figure 1 Comparison of transmitter density for a single TV broadcast frequency between US and UK (maps at same scale)

2.2 Protection of Existing Users of the "White Space" Frequencies

Licence-exempt use of white space frequencies requires a way to identify and avoid frequencies that are being used locally for TV transmission or other licensed use such as wireless microphones. This can be done either by automatically sensing and avoiding frequencies already in use (auto-sensing) or referring to a geographic database of TV transmitters and other licensed use (geolocation). Auto-sensing requires a highly sensitive receiver that can detect signal levels much lower than would normally be the case for low cost consumer devices and is not considered viable in the short to medium term. Geolocation also presents challenges but is currently the favoured approach in the UK and rest of Europe.

2.3 International Technical Standards

Development of a global standard for white space devices is being undertaken by the US-based IEEE working group 802.22. There are likely to be three classes of white space device defined under the emerging 802.22 standards, namely one fixed and two types of portable device (mode I and mode II). Portable mode II devices would be similar to existing Wi-Fi access points, providing wireless connectivity to Portable Mode I client devices which would typically include wireless enabled PCs, USB dongles, mobile handsets or audiovisual devices.

2.4 Example of a prototype UHF wireless network

One example of a Wi-Fi type system intended for deployment in white space spectrum is "WhiteFi", conceived by researchers from Microsoft and Harvard University[1]. The WhiteFi prototype comprises a conventional Wi-Fi card, a UHF band converter, and a software defined radio (SDR). According to the researchers,

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[1] "White Space Networking with Wi-Fi like Connectivity", P. Bahly, R. Chandray, T. Moscibroday, R. Murtyz, M. Welshz, Proc. ACM SIGCOMM 2009, Aug. 2009, pp. 27-38

several wireless card vendors are considering submitting versions of Wi-Fi to the IEEE standards body for white space networking.

3 ASSESSING THE POTENTIAL BENEFITS OF WHITE SPACE WIRELESS NETWORKS

3.1 Introduction

The principal benefit that white space frequencies would deliver is improved coverage, due to the lower signal attenuation. Theoretically, migrating a Wi-Fi system from 2.4 GHz to the white space frequencies has the potential to more than double the operational range in a typical indoor environment, from approximately 50 – 100 metres to 125 – 250 metres. However this ignores the practical problem of realising efficient antenna devices that can cover the white space frequencies.

For optimal performance with a conventional antenna the physical size in at least one dimension should be approaching a quarter of the wavelength at the frequency of operation. At 2.4 GHz this equates to a approximately 3 cm, which will fit comfortably within compact devices such as USB dongles or mobile handsets. At 500 MHz, the antenna size would need to be 15 cm, appropriate for a laptop or desktop modem, but not for a handheld device or dongle.

A further problem with white space frequencies is the bandwidth that must be covered. 2.4 GHz networks operate over a bandwidth of 3.4% of the centre frequency and 5 GHz devices up to 18%. By comparison, a UHF white space device covering the entire UHF band (470 – 790 MHz) implies a bandwidth of 50% of the centre frequency. Conventional antennas will work well over bandwidths of up to 10% and can offer reasonable performance up to 20%, but efficiency degrades considerably at wider bandwidths.

There has been little if any development work to date on compact broadband antennas specifically for white space devices, but products have been developed for the nascent mobile TV market, which also requires small handheld devices to operate over the entire TV broadcast band. An example is the Antenova tuneable mobile TV antenna, which has dimensions of 50 x 15 mm[2]. Gain is optimal at the top of the frequency range, and ranges from -3 dBi at 860 Hz to – 7 dBi at 470 MHz. This is between 3 and 7 dB less than the 0 dBi typically achievable at 2.4 GHz.

The impact of the reduced antenna gain in the UHF band is to offset partially the benefit of the improved radio propagation environment in this band, so that the range improvement is reduced to approximately 50% relative to 2.4 GHz. Use of a lower frequency band also makes it more challenging to deploy smart antenna

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[2] At the time of writing preliminary data on this product was available from the Antenova web site at Hwww.antenova.com/?id=1535H

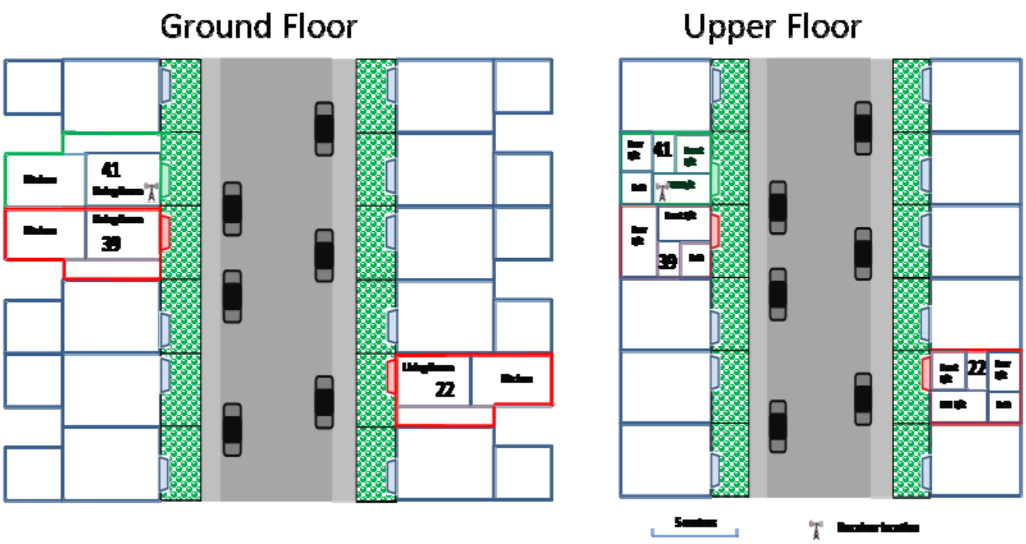
systems such as MIMO[3] which are increasingly used to optimise performance of Wi-Fi systems, because of the larger physical dimensions involved.

3.2 Assessing the benefits in a typical residential scenario

To compare white space frequencies with existing Wi-Fi frequencies we undertook a series of measurements to compare the signal level on a room-by-room basis and at street level in the vicinity of the wireless network. We used a spectrum analyser to measure the received signal level at two fixed locations (corresponding to where a Wi-Fi access point might be located), while a mobile transmitter was moved at random around a series of rooms in three neighbouring suburban houses. The receiver and transmitter were each connected to a nominally omnidirectional antenna.

An in-house software package was used to log the signal level at 200 millisecond intervals, with typically 200 - 300 readings taken for each location. Appropriate correction factors were then applied to normalise the transmitter powers to the 100 milliwatts specified for a Wi-Fi Access Point and to allow for the different assumed antenna gains for wireless network equipment in the two frequency bands (as discussed above). The approximate layout of the three houses is shown below.

Figure 2: Layout of houses used for coverage measurements



Two series of measurements were taken, one with the spectrum analyser located by the front window of no.41 and the other taken with the analyser located in the attic room of number 41. Measurements were undertaken at two frequencies, namely 2400 MHz and 498 MHz, operating under a non-operational licence issued by Ofcom.

[3] Multiple Input Multiple Output

The tables below summarise the measured receive signal level at the two frequencies in various locations within the three houses, with the receiver first located by the front window of the living room in No 41 and secondly located in the attic room of No 41 (above the first floor middle bedroom). For convenience, the signal levels have been categorised according to the likely level of performance of the wireless network (this is based on the specification of a typical 802.11g wireless device). The three categories are:

- Green: signal level above -74 dBm, full rated throughput should be possible
- Amber: signal level between -90 and -74 dBm, network devices should be operable but throughput will be sub-optimal
- Red: signal level below -90 dBm, network devices unlikely to operate reliably

It can be seen that at 2400 MHz, network coverage at 2.4 GHz becomes increasingly patchy beyond the confines of the house where the receiver is based, At 500 MHz, however, good coverage is found to extend not only throughout the two adjacent houses (Nos. 39 and 41) but also into the separate dwelling across the road at No. 22. The implication is that the lower frequency band would provide good coverage throughout even a very large residential building and would be likely to extend to outbuildings that would be beyond the reach of the 2400 MHz signal.

Table 1: Measured signal levels, receiver located by living room window at No 41

	498 MHz		2400 MHz		
Location	**Rx Sig**	**Std Dev**	**Rx Sig**	**Std Dev**	**Difference**
No 41					
Kitchen	-46. dBm	5.9 dBm	-55.3 dBm	7.5 dBm	9.3 dB
Back bedroom	-43.6 dBm	5.9 dBm	-72. dBm	5.7 dBm	28.5 dB
Middle bedroom	-42.5 dBm	5.5 dBm	-62.3 dBm	5.5 dBm	19.8 dB
Front bedroom	-38.1 dBm	4.8 dBm	-59.4 dBm	5.8 dBm	21.3 dB
No 39					
Living room	-38.9 dBm	5.3 dBm	-62.1 dBm	8.4 dBm	23.2 dB
Kitchen	-51.8 dBm	7.1 dBm	-79.3 dBm	6.2 dBm	27.5 dB
Back bedroom	-57.8 dBm	5.9 dBm	-88.6 dBm	4.9 dBm	30.9 dB
Bathroom	-46.7 dBm	6.2 dBm	-71.6 dBm	6. dBm	25. dB
Front bedroom	-42.3 dBm	5.7 dBm	-65.1 dBm	5.7 dBm	22.8 dB
No 22					
Living room	-62.1 dBm	5.1 dBm	-81.2 dBm	5.7 dBm	19.1 dB
Kitchen	-72.2 dBm	6.2 dBm	-92.3 dBm	5.1 dBm	20.1 dB
Back bedroom	-68.4 dBm	5.4 dBm	-98. dBm	3.6 dBm	29.6 dB
Middle bedroom	-60.3 dBm	5.9 dBm	-89.8 dBm	4.6 dBm	29.5 dB
Front bedroom	-56.2 dBm	5.5 dBm	-77.9 dBm	7.7 dBm	21.7 dB

Table 2: Measured signal levels, receiver located in attic room at No 41

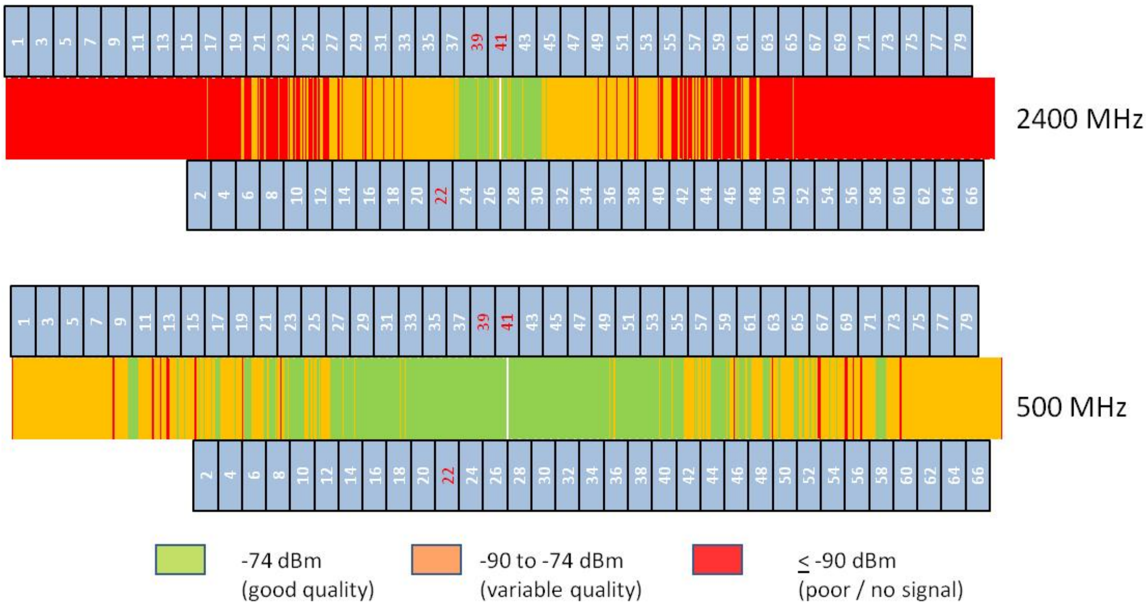
	498 MHz		2400 MHz		
Location	**Rx Sig**	**Std Dev**	**Rx Sig**	**Std Dev**	**Difference**
No 41					
Living Room	-45.8 dBm	5.7 dBm	-62.7 dBm	5.8 dBm	16.9 dB
Kitchen	-51.9 dBm	6.2 dBm	-75.6 dBm	6.5 dBm	23.7 dB
Back bedroom	-49.6 dBm	6.4 dBm	-72.8 dBm	5.4 dBm	23.2 dB
Middle bedroom	-36. dBm	4.4 dBm	-49.7 dBm	6.1 dBm	13.7 dB
Front bedroom	-36.9 dBm	4.5 dBm	-51.7 dBm	5.1 dBm	14.8 dB
No 39					
Living room	-53.4 dBm	5.7 dBm	-77.4 dBm	5.7 dBm	24. dB
Kitchen	-63.7 dBm	5.9 dBm	-90. dBm	4.9 dBm	26.3 dB
Back bedroom	-57.1 dBm	5.4 dBm	-86.2 dBm	4.4 dBm	29.1 dB
Bathroom	-45.9 dBm	5.3 dBm	-69.4 dBm	5.6 dBm	23.5 dB
Front bedroom	-47.7 dBm	6.1 dBm	-70.8 dBm	6.1 dBm	23.1 dB
No 22					
Living room	-66.8 dBm	6.1 dBm	-89.2 dBm	5.2 dBm	22.4 dB
Kitchen	-78. dBm	6.2 dBm	-100.8 dBm	3.1 dBm	22.8 dB
Back bedroom	-73.5 dBm	5.9 dBm	-98.7 dBm	3.2 dBm	25.2 dB
Middle bedroom	-63.8 dBm	5.2 dBm	-88.7 dBm	5. dBm	24.9 dB
Front bedroom	-59.4 dBm	7.3 dBm	-77.9 dBm	7.2 dBm	18.5 dB

3.3 Comparing outdoor coverage in the vicinity of the wireless network

There have been recent initiatives to provide community Wi-Fi access using subscribers' home network access points to complement existing public "hot spots". For example, in the UK, BT has partnered with the international community Wi-Fi facilitator FON to enable BT broadband subscribers to access the wireless network of any other subscriber who has subscribed to the service. In practice the utility of such a service will clearly depend on how far a typical Wi-Fi signal will extend beyond the home premises it is primarily intended to serve. As part of our measurement exercise we therefore monitored the signal level along the street at each of the two frequencies.

The figure below shows how the signal level varies along the street at the two test frequencies. It can be seen that even after allowing for the reduced antenna efficiency there is a significant improvement in network availability at street level, which could make the lower frequency band particularly attractive for facilitating community wireless networks as an alternative mobile broadband connectivity platform, or to provide coverage in areas where it is not commercially attractive to public mobile operators.

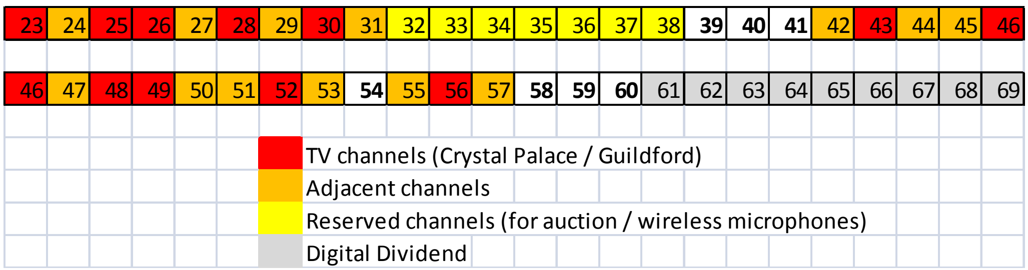
Figure 3: Variation of outdoor signal quality along street



4 Spectrum Availability for White Space Devices

The UHF TV band comprises 392 MHz, however only a limited amount of this bandwidth would be available as "white spaces" at any particular location. The chart below indicates the frequencies that are likely to be available at a typical suburban location. Seven TV channels are available; a total bandwidth of 56 MHz. Additional spectrum would be available in rural locations that are served by only a single TV transmitter; however the above figure is probably more representative of the areas where demand for wireless home networking is likely to be greatest.

Figure 4: Availability of TV channels in a typical suburban location (Cobham, Surrey)



By comparison, the available spectrum in the 2.4 GHz band is 83.5 MHz and in the 5 GHz band up to 455 MHz is available. The deployment of the UHF band is therefore likely to be complementary to, rather than a substitute for, these higher bands, providing improved coverage where this is needed, for example in larger residential premises.

Based on current Wi-Fi technology capabilities we estimate that a single 8 MHz channel would deliver a peak usable bit rate of between 9 and 36 Mbps depending on whether 802.11 g or 802.11n technology is deployed, with more typical values of 2 – 14 Mbps in a multi-user environment[4]. These rates could be increased by combining multiple channels, depending on local availability. For example, figure three shows that two contiguous three channel blocks are available, which would provide capacity slightly greater than existing 20 MHz channels at 2.4 GHz.

5 POTENTIAL INTERFERENCE ISSUES

Deployment of wireless networks in the UHF TV band presents three potential interference scenarios, namely:

i) Interference to licensed users of the band (TV and wireless microphones)

ii) Interference to other domestic equipment (e.g. cable TV receivers)

iii) Interference between white space devices

As already noted, avoidance of interference to licensed TV and wireless microphone users is likely to require access to an on-line database of frequency use which would be updated on a regular basis (under current Ofcom proposals at least every two hours). The white space network would need to identify its location with reasonable accuracy (100 metres resolution). Because of the relatively small area covered by in-home wireless networks, it should be sufficient for only the access point location to be specified, client devices being assigned the same location as the access point.

A number of studies around the world have indicated that white space devices could cause interference to other domestic audiovisual equipment, in particular cable TV receivers which operate on the same frequencies. There is also a risk of interference to other equipment that is connected using HDMI cables. The risk of interference is highly dependent on the individual equipment involved. For equipment that just meets the minimum interference immunity specified in European standards we estimate that interference could arise if a white space device operates within 4 metre, whereas the best performing equipment tested could tolerate white space devices at a distance of 1 metre or less. There may therefore be a need to tighten immunity standards for cable TV receivers and other audiovisual equipment if white space devices are to be widely deployed in the home and we recommend further work in this area.

Our measurement results indicate that interference between nearby wireless networks operating on the same frequency would be slightly higher at 500 MHz, but the effect of this would be mitigated by the collision avoidance algorithms built into

[4] The maxima are based on a channel width of 8 MHz and spectrum efficiency of 1.1 bits/Hz and 4.5 bits/Hz respectively. The shared environment figures apply a multiplier of 20 – 40% per user to these maxima

the WiFi standards and deployment of multi-band devices that would default to the highest available frequency band, using the lower white space frequencies only where necessary to meet a specific coverage requirement.

6 CONCLUSIONS

6.1 Benefits of White Space Frequencies for Home Networks

Our analysis and measurement results both confirm that Wi-Fi type networks deployed on the UHF white space frequencies would provide substantially better coverage both in indoor environments and at street level outdoors. The indoor coverage improvement would particularly benefit larger residential premises whilst the outdoor improvement could facilitate community wireless broadband services in areas lacking other mobile broadband coverage.

6.2 Regulatory Considerations

There are three key areas where regulatory clarity is required in order for development of commercial white space devices and networks to proceed, namely:

i) Agreement of technical standards to facilitate interoperability, akin to the existing 802.11 family of standards for Wi-Fi equipment – this is currently being progressed within the IEEE 802.22 standards group but the focus is primarily on higher power regional area networks. For local area (Wi-Fi type) applications the 802.11 standards group may be a more appropriate forum.

ii) Agreement of technical parameters for white space devices to ensure the protection of other licensed users of white space spectrum, notably TV broadcasting and wireless microphones. In Europe this is being addressed by CEPT Working Group SE43, in which the UK regulator Ofcom is playing a proactive role.

iii) Establishment of a national database of existing licensed users – the parameters of such a database are currently being addressed within WG SE43 but implementation will be managed at a national basis, in the UK by Ofcom (though management of the database may be contracted to a third party).

We also believe there is a need for more work to investigate the compatibility of residential white space device use with other audiovisual devices, particularly cable TV receivers and the adoption of more stringent interference immunity standards for the latter may be required.

6.3 Enabling Technology Requirements

Much of the technology required to deploy white space devices in home network applications already exists in the form of existing 802.11 hardware, which in principle could be “re-banded” to the white space frequencies. The key area where further development is likely to be required is in relation to antennae and other passive components, to accommodate the wide tuning bandwidth and lower frequencies compared to existing 2.4 GHz and 5 GHz devices. Some modification to the 802.11 channel selection protocols may also be required to enable automatic selection of the highest available frequency band, so that the limited spectrum available in the UHF band can be reserved for those situations where it is actually necessary (i.e. where insufficient coverage is provided in the existing higher frequency bands).