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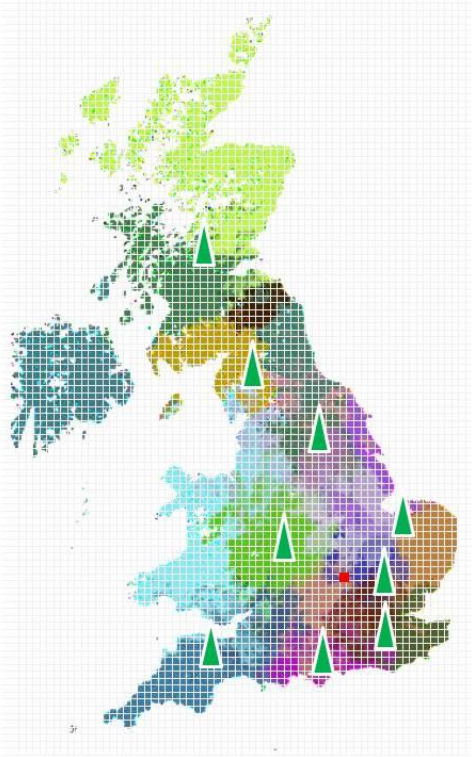
Audit of Methods for Calculating White Space Spectrum Availability



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We seek to demystify wireless and help our customers get the best from it, by understanding their business needs and using our deep knowledge of wireless to create an effective wireless strategy, implementation plan and management process.

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Executive summary

An audit of a BBC approach to calculating TV white space availability finds that the methods and assumptions used are largely consistent with those defined by Ofcom for their TV White Spaces Study. That both methodologies were developed through collaboration in an Ofcom led technical working group is considered a further positive indicator of consistency.

A small number of minor inconsistencies were identified. The impact of these has not been directly assessed but these were not expected to have a major impact on the results.

Two additional inconsistencies were identified which may result in lower estimates of White Space availability from the BBC tool, compared to the Ofcom approach:

1) The BBC model uses only suburban propagation models for WSD-TV interference, whereas Ofcom specifies an urban model should be used when evaluating interference into urban areas. The higher loss of the urban model would increase the isolation between the WSD[1] and TV and increase likelihood that a given channel would be available for WSD usage. The resulting underestimate of TV white space in urban areas might be heavily weighted in the overall results due to the high density of households per 'pixel' compared to other geo-types.
2) Different criteria are used to define areas of TV coverage. Ofcom state that a 'pixel' must have ≥70% probability of successfully receiving a TV signal to be considered 'covered' and thus need protecting from WSD interference. The BBC model allows down to a 50% probability, as captured by the 'DPSA[2] layers' . Whilst this might even be a more accurate approach, it is not the same as that defined in Ofcom's documented approach. The BBC method would likely result in wider TV coverage than the Ofcom method, which in turn would mean lower availability of TV white space.

Although not specified by Ofcom and thus beyond the scope of the audit, we note that the BBC model assumes WSDs only in locations adjacent to residential households and thus the availability results may not be applicable to other types of WS usage, such as a Machine to Machine network.

The audit was based on documentation and discussions with those involved in the implementation; we have not run or reviewed the software tool itself. As with any simulation activity, it is advisable to cross check results against an alternative implementation.

[1] WSD: White Space Device
[2] DSPA: Digital Signal Planning Areas: define coverage of the different TV transmissions

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1. Introduction

Following a consultation [1], Ofcom is preparing a statement on the potential uses of the 600MHz and 700MHz band. Part of this work includes an analysis of the availability of TV White Spaces, where White Space Devices (WSDs) may transmit and communicate provided they do not significant degradation to the TV service.

A tool has been developed by the BBC and Arqiva to assess the amount of white space spectrum available in the UK for a number of different TV planning scenarios. The purpose of this audit is to check whether the methods and assumptions used by the BBC tool are consistent with those defined by Ofcom for their TV White Spaces project.

Our audit has been based on the following sources:

- Documents supplied by the BBC/Arqiva
- Documents supplied by Ofcom
- Discussions with BBC and Ofcom

We have not run or reviewed the actual software as this was considered to be beyond the scope of this audit, so our findings assume the accuracy of the above sources. As with any simulation activity, the potential for errors exists and so it would be advisable to sanity check the results against other implementations. In particular we would expect Ofcom to maintain its own reference implementation of its specified methodology.

1.1 Audit Methodology

The audit compares the BBC approach with that defined by Ofcom and identifies aspects as either consistent or inconsistent as follows:

- **Consistent:**
  - The method or assumption described by the BBC is consistent with that described by Ofcom in [2]
- **Inconsistent:**
  - The method or assumptions described by the BBC is not consistent that that described by Ofcom.
  - In this case we consider the likely impact to the results and whether it is likely to lead to an optimistic or pessimistic estimate of the amount of white space available compared to the approach described by Ofcom.
  - We note that an inconsistent method or assumption does not necessarily mean it is incorrect or inaccurate, simply that it is not the same as that described by Ofcom.

The audit is based on examination of documents from Ofcom and the BBC given in the references, supplemented with telephone and email discussions with their authors for further clarification. The following elements of the Ofcom methodology were out of scope for the scenarios of interest and so were not assessed:

- The distribution of locations of White Space Devices
- TV Configurations other than the 'vanilla' roof-top antenna.
- White space device classes with significant ACLR (Adjacent Channel Leakage Ratio)

1.2 BBC participation in Ofcom's White Space Technical Working Group

During 2012, Ofcom led a group to discuss methods and assumptions to be used in white space analyses. The group included several contributors including members of the BBC team which implemented the models being discussed here. The slides outlining Ofcom's method and assumptions [2] contain acknowledged contributions from the BBC team on various aspects of the analysis. We consider participation in this group to be a positive indicator of consistency of the BBC's approach with Ofcom's.

2. Method described by Ofcom

2.1 Overview

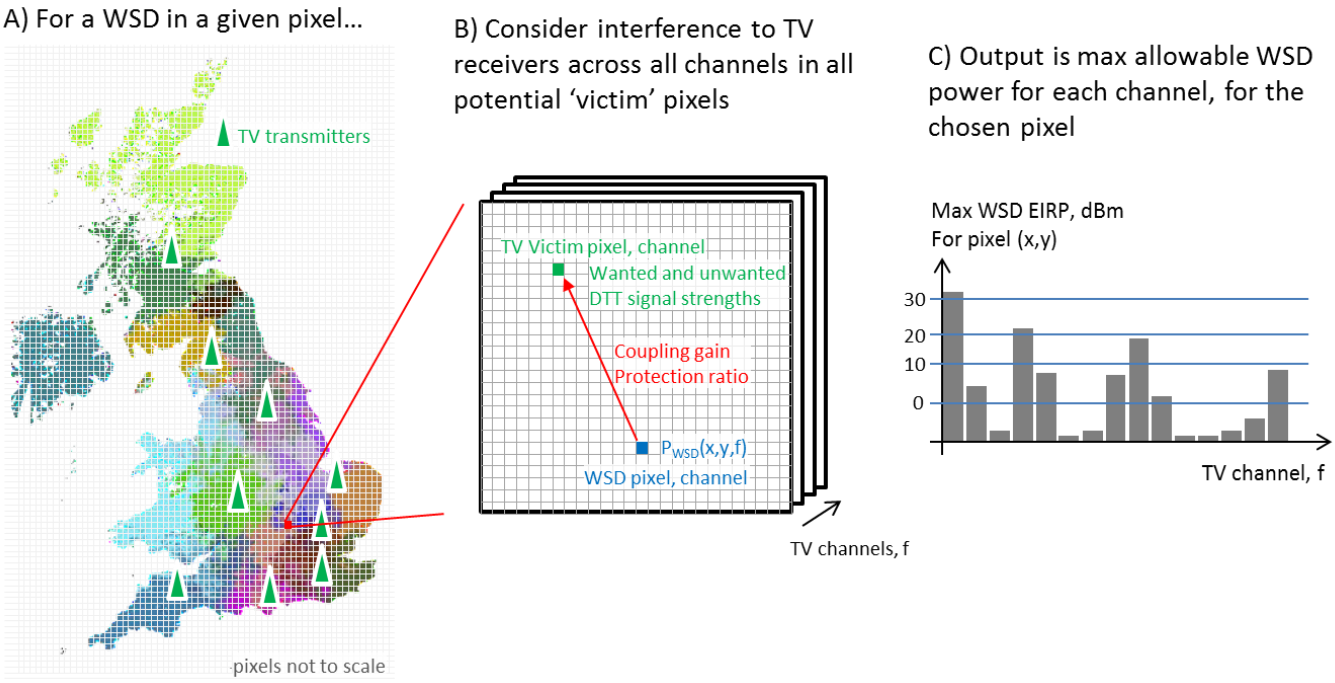

Figure 1: Overview of method to evaluate white space

Figure 1 provides a high level illustration of the method used to evaluate white space availability in the UK. The overall aim is to identify for a WSD in a given pixel, the maximum power it can transmit on each TV channel such that would not cause a significant impact to the TV service in any pixel or channel. C) illustrates the form of the output for a given pixel. B) shows some of the key considerations when evaluating interference to the TV service: A WSD transmission in a given pixel on a given channel may cause interference to TV receivers in the same or nearby pixels on the same or other TV channels. Coupling gain is a function of pixel separation, antenna orientations and heights. The protection ratio is a function of the wanted DTT signal strength and the frequency offset between WSD and TV channels. The method must consider all combinations of pixels and channels to ensure the TV service is sufficiently protected, however simplifications are needed here to make the computations tractable.

2.2 Pseudo-code description of the method

A pseudo-code style description of the method is provided below with numbers identifying each step . The numbers 3.1 to 3.3.2.4 indicate the sections of this report in which that step is analysed. The audit will be organised according to the methods and assumptions required for each step.

Identify white space availability across the UK:
3.1 For each potential WSD pixel and TV channel:
3.2 Evaluate P_{WSD}: Max allowable EIRP of WSD in that channel and pixel
3.3 For each potential TV victim pixel:
3.3.1 Calculate coupling gain: function of (WSD pixel, victim TV pixel)
3.3.2 For each victim TV channel calculate:
3.3.2.1 P_S,P_U, power of wanted TV signal and unwanted interfering TV signals
3.3.2.2 Location probability: function of (P_S, P_{Smin}, P_U)
3.3.2.3 ACIR: function of (WSD & TV frequency offset, DTT signal power P_S)
3.3.2.4 Calculate WSD power causing ≤1% reduction in location probability
3.3.3 Next (victim TV channel)
3.3.4 Gives Max P_{WSD} whilst protecting all channels in the victim pixel
3.4 Next (victim TV pixel)
3.5 Gives Max P_{WSD} whilst protecting all channels in all victim pixels
3.6 Next (potential WSD pixel)

3. Identify white space availability across the UK

The following sections 3.1 - 3.3.2.4 provide further detail on the methods and assumptions under each step of the pseudo-code description given earlier. Steps 3.3.3 to 3.6 are included for completeness but do not introduce new methods or assumptions to be checked for consistency.

3.1 For each potential WSD pixel and TV channel

Distribution of WSD Locations: **Not specified by Ofcom**
The BBC model quantifies WS availability as the percentage of UK households that could transmit over a given number of WS channels at a given power [3]. The search for WS availability is therefore limited to pixels which are populated, and weighted by the number of households in that pixel. The availability figures are therefore indicative of domestic WS usage (such as a WLAN), but may not be directly applicable to other types, such as Machine to Machine (M2M) network where transmitters are not associated with households.

Channels: consistent
Results from the BBC model are for given a variety of channel usage scenarios between channels 21-60, which are consistent with the range specified in [2] p3.

The BBC model is consistent with Ofcom in that channel 38 is reserved for PMSE (Programme Making and Special Events).

3.2 Evaluate P_{WSD}: Max allowable EIRP of WSD in that channel and pixel

Allowable WSD Radiated power: potential for inconsistency
BBC state WSD powers in ERP whilst Ofcom use EIRP (Effective Isotropically Radiated Power). The BBC equation (5) in [5] (below) describing coupling gain gives the maximum

WSD transmit power in ERP (Effective Radiated Power). This ERP is referenced to the gain of a dipole (0dBd = 2.15dBi) rather than an isotropic radiator (0dBi). So is 2.15dB lower than an equivalent EIRP.

$$P_{IB(dBm)}^{WSD} = m_k - r(\Delta f, m_s)_{(dB)} + P_l - G_{r(dBi)} - 2.15 \quad (5)$$

The Ofcom document, in common with typical specifications for consumer devices like Wi-Fi Access Points, use EIRP [2], p18-21. Where BBC results for allowable WSD power are expressed in ERP (relative to a dipole), then they might be misinterpreted as being lower than they actually are: for example 30dBm ERP corresponds to 32.1 dBm EIRP.

Since pointing out this apparent discrepancy, Ofcom have informed us that the BBC have confirmed that results presented in [3] are adjusted to give allowable WSD powers in the normal units of EIRP, so that the results should be accurate, although the documentation needs to be aligned with this.

3.3 For each potential TV victim pixel

Conditions for selecting potential TV victim pixels: inconsistent
The BBC state the following conditions are used to identify whether a pixel should be protected from WSD interference:

- Is protected by a DPSA[3] layer, ***and***
- Is populated (in the UKPM sense, i.e. has an entry in the Postcode Checker Database) ***and***
- Its Location % > 50%

The first two conditions are consistent with Ofcom approach [2] p46,66, however the last is not, as Ofcom assume >70% coverage is needed to be protected. The BBC provided the following explanation:

> "The protected pixels (actually pixel-channel combinations) are defined from the DPSA layers. The DPSA method requires that the coverage probability of a pixel is >70% for all the relevant services. However, the 70% criterion may not be universal. For example if a station has PSB_1,2,3 =80% and COM_4,5,6 = 60%, it may well be in the PSB DPSA. In this case however we protect ALL 6 services, even if they are <70% (as long as they are >50%). The rationale behind it is that, since this subscriber has a partial service, and a fair chance of receiving a full service, it will be unfair to take it from him."

Whilst it seems reasonable that the DSPA layer incorporates the location probability, this is not the approach described in [2] p46, 66. The lower required location probability down to 50% means wider DTT coverage, and thus more pixels to protect at lower field strengths. This would reduce white space availability.

Simplifications to limit search for potential victim pixels: Reasonable assumptions

[3] Digital Planning Service Area

The identification of white space should ensure that all TV services anywhere in the UK are sufficiently protected. In practice the impact of white space interference will become insignificant beyond a certain range and thus it should not be necessary to search for victim pixels beyond this.

The BBC describe an exhaustive search over a 50km radius as this was considered the reach of non-negligible interference from a 1watt EIRP transmitter with Hata Suburban propagation. Although the Ofcom document does not specify any such simplification method, this seems reasonable.

3.3.1 Calculate coupling gain: function of (WSD pixel, victim TV pixel)

Coupling Gain Method: consistent
The BBC includes the same terms in the coupling gain: Antenna angular discriminations for both TV and WSD antennas, propagation loss and receive antenna directivity. We note that transmit antenna directivity is not included as the radiated power is required. We note different units of radiated power are used in the two approaches as described earlier.

Coupling gain for same and adjacent pixels: minor inconsistency

> "The mean value for the coupling gain when both WSD and the victim DTT are in the same pixel, was computed to be -49.16 dB at 474 MHz", BBC[5]

[2] p64 shows 49.1 dB, which is marginally lower loss. BBC result with higher path loss for WSD-DTT means slightly more white space. A difference of 0.06dB in practice is negligible and so the approaches are considered consistent.

Propagation Models for beyond 1st tier: Inconsistent
Ofcom [2] p32 & 65 specifies use of the extended Hata suburban or urban model according to the clutter type of the victim pixel. The BBC model uses only the Hata Suburban model. The likely implication is that suburban model has less path loss, coupling gains will be lower, giving pessimistic estimate of white space availability in urban areas.

Antenna heights and gains: **consistent for 'vanilla' or default configuration**
Both BBC and Ofcom assume a 'rooftop' TV antenna height of 10m, and a WSD height of max(clutter height, 10m). Terrain heights are not used [2] p65. Both analyses use the same TV antenna gain (9.15dBi) and radiation pattern. Protection of Indoor set-top TV is not in scope.

3.3.2 For each victim TV channel calculate

The following steps are considered for all potential TV channels. BBC assumptions on channels are consistent as described earlier.

3.3.2.1 P_S,P_U, power of wanted TV signal and unwanted interfering TV signals

Format of TV signal description: consistent
Field strengths for the TV signals are obtained from the UKPM[4] which is managed by the BBC and Arqiva. The process by which these are calculated is not within the scope of this audit [2] p46. The TV signals are characterised by a log-normal distribution with a given mean and standard deviation.

[4] UK Planning Model for DTT coverage predictions

3.3.2.2 TV Location probability: function of (P_S, P_{Smin}, P_U)

Method to Calculate TV location probability: consistent
The location probability is determined from wanted and interfering signals, and the minimum wanted TV signal power. The mean and standard deviations of both wanted and unwanted signals are taken into account. The BBC method is consistent with Ofcom's.

Minimum Required TV Signal, P_{Smin}: consistent
The BBC give a required field strength of 46.8dBμV/m in [5]. Ofcom in [2] p79 give 46.62 dBμV/m (for JPP variant I) noting that JPP cites the 46.8dB figure consistent with the BBC. All figures quoted are for 500MHz.

Frequency Dependency of P_{Smin}: minor inconsistency
Ofcom: "For channel 39 and above, ES,min 10 m is increased by 1 dB", [2] p79
BBC: **"**For channels above 39, P_{Smin} is one dB higher." [5]

The BBC model will therefore assume DTT receivers are more sensitive in channel 39, and thus potentially allow more white space (unless this increases DTT coverage area, in which case white space could be reduced)

3.3.2.3 ACIR: function of (WSD & TV frequency offset, DTT signal power P_S)

ACIR values: Consistent
ACIR (Adjacent Channel Interference Ratio) is the combination of both ACLR (Adjacent Channel Leakage Ratio) and ACS (Adjacent Channel Selectivity). Both Ofcom and the BBC indicate that only the ACS will be taken into account. Ofcom indicate that this is because ACLR is negligible. BBC state that if ACLR was comparable to ACS an error of up to 3dB would be incurred by the assumption. Ultimately, the BBC uses the same table of relative ACIR values as included in Ofcom [2] p69, as well as the absolute value of R(0) of 17dB, and so is consistent.

3.3.2.4 Calculate WSD power causing ≤1% reduction in location probability

Iterative Method to Calculate Max WSD power: consistent
One of the more challenging steps in the modelling is to evaluate the maximum allowable WSD power that will not cause significant degradation to the TV service. The BBC definition of significant is consistent with Ofcom's which is <1% reduction in location probability. No closed form solution to the derivation of PWSD is found, and an iterative approach using the Schwartz-Yeh method is proposed in the annex of [4]. The formulation and solution of the problem in the BBC document [5] is consistent with that by Ofcom in [2] (p49,51).

Interaction of location probability with 70% coverage criterion: Reasonable assumption
Given the Ofcom criteria that pixels must have >70% location probability, the question arises on whether WSD interference is allowed to push a pixel from just above 70% to below 70% and thus no longer be in TV coverage.

- Not allowing this could mean pixels only just clear of 70% might be highly sensitive to very small amounts of WSD interference, causing pessimistic estimates of WS availability
- Allowing this could create a conundrum: high WSD interference forces pixels to be out of DTT service, and thus no longer need protecting.

The BBC provided the following description:

> "We do allow the coverage probability to go below 70% (or 50%) in the presence of WSD interference. We believe that the decision on whether a pixel (or pixel-channel)

is to be protected should come from the DPSA, otherwise you have issues like the one mentioned. The alternative is to use less than 1% degradation for pixels with coverage probability in the (70-71) range, but this will complicate the algorithms and the amount of required storage", BBC

Given that the BBC approach uses only DSPA layers to define whether a pixel is covered, the approach is sensible and avoids highly sensitive pixels. This suggests that the 70% criterion for TV coverage is either not applicable, or only applicable prior to considering interference from WSDs.

3.4 Remaining Steps 3.3.3 – 3.6

No further methods or assumptions included in this, or any of the remaining steps.

3.3.3 Next (victim TV channel)
3.3.4 Gives Max P_{WSD} whilst protecting all channels in the victim pixel
3.4 Next (victim TV pixel)
3.5 Gives Max P_{WSD} whilst protecting all channels in all victim pixels
3.6 Next (potential WSD pixel)

4. Summary of Consistency

Table 1 provides a summary of the audit, the aspects compared between BBC and Ofcom approaches, whether they are consistent, and the likely impact of any inconsistencies.

Table 1: Summary of Consistency of BBC's modelling approach to Ofcom's

Step	Aspect	BBC approach w.r.t. Ofcom's	Impact of inconsistency
3.1	TV channels 20-62	Consistent	
3.1	Ch 38 reserved for PMSE	Consistent	
3.2	Allowable WSD Power in ERP rather than EIRP	Potential Inconsistency	WSD powers in ERP appear 2.1dB lower than an EIRP figure would be. Since pointing out this apparent discrepancy, Ofcom have informed us that the BBC have confirmed that results presented are adjusted to give allowable WSD powers in the normal units of EIRP, so that the results should be accurate, although the documentation needs to be aligned with this
3.3	Conditions for TV victim pixels	Inconsistent	BBC assume wider TV coverage, which may reduce WS availability
3.3.1	Coupling gain method	Consistent	
3.3.1	Coupling gain for same & adjacent pixels	Consistent in practice	0.06dB discrepancy
3.3.1	Propagation models for beyond 1st tier	Inconsistent	BBC may underestimate WS availability in urban areas
3.3.1	Antenna heights and gains	Consistent	
3.3.2.1	Format of TV signal description	Consistent	
3.3.2.2	Method to calculate TV location probability	Consistent	
3.3.2.2	Minimum required TV signal strength (P_{Smin})	Consistent	
3.3.2.2	Frequency dependency of P_{Smin}	Minor Inconsistency	small increase in WS availability
3.3.2.3	ACIR values	Consistent	
3.3.2.4	Iterative calculation of Max WSD Power for <1% location probability	Consistent	

5. Conclusions

The audit finds that the BBC approach is largely consistent with that described by Ofcom. Both methodologies were developed together through collaboration in an Ofcom led technical working group. A small number of inconsistencies were identified. The impact of these has not been directly assessed but these were not expected to have a major impact on the results of the BBC's study on white space availability in [4]. We note that the allowable WSD radiated powers described in [4] are expressed in ERP which is 2.15 dB lower than an equivalent EIRP. The BBC have responded via Ofcom that this is not the case and that results presented in [3] are given in the normal units of EIRP.

Two inconsistencies were identified which might lead to non-trivial reductions in white space availabilities as follows:

1) **Conditions to determine TV coverage**: Ofcom states that to be considered covered, a pixel must have higher than 70% location probability whereas the BBC approach assumes figures as low as 50% are acceptable, and that the DPSA layers alone should determine whether a pixel is considered covered or not. The BBC assumption of a weaker required signal means wider coverage for TV, and thus reduced availability of white space. That said, the BBC approach avoids a difficult boundary condition conundrum where pixels with marginally over 70% location probability could be pushed out of coverage by WSD interference.
2) **Propagation models:** Ofcom state that the WSD to TV signal path should use suburban or urban propagation models, depending on the clutter type of the victim pixel. The BBC approach uses only a suburban propagation model, which is expected in general to have lower path loss than the urban. The result is that the higher path loss seen in urban areas will not be taken into account, and WSD interference will be higher than if an urban propagation model were used. The BBC approach will therefore underestimate TV white space availability in urban areas. White space availability in urban areas is expected to be low, so it is possible there is little to be lost. On the other hand, the high count of households per pixel in urban areas will mean greater weighting is applied to urban results.

That there are inconsistencies does not necessarily mean that the BBC approach is incorrect or inaccurate, only that it differs from the method described by Ofcom.

Although not specified by Ofcom and thus beyond the scope of the audit, the distribution of WSD locations assumed in the BBC model influences WS availability results. In the BBC model, WSDs were assumed to exist only in households in populated pixels. The WS availability results in [4] are therefore representative of domestic white space usage, and not necessarily usages such as an M2M (Machine to Machine) network.

Finally, the audit was based on documentation of the methods and discussions with the authors. We have not run the software itself, and as with any simulation activity, a sanity check of results against an alternative implementation is advisable. In particular we would expect Ofcom to maintain its own reference implementation of its specified methodology.

References

[1] “Securing long term benefits from scarce spectrum resources - A strategy for UHF bands IV and V”, Ofcom, 29/03/2012, http://stakeholders.ofcom.org.uk/consultations/uhf-strategy/

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[3] “*Impact of DTT networks in 600 MHz on WS (White Space) channel availability in UHF TV bands*”, BBC and Arqiva, v1.2, 20th Sept 2012

[4] “*Estimation of Spectrum Availability For White Space Devices*” K.Tsioumparakis, D.J.Darlington, TVWS Discussion Document 8-2-2012,

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