COMPATIBILITY CHALLENGES FOR BROADCAST NETWORKS AND WHITE SPACE DEVICES

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ABSTRACT

Digital Switch-Over plans have driven a thorough review of UHF spectrum and how it might be used. The deployment of low power white space devices (WSDs) has potential to deliver improved WiFi systems for mobile broadband and a new platform for multimedia streaming in the home. The FCC has recently approved plans for new fixed and mobile devices, based on a combination of spectrum sensing and geolocation. Devices are expected to appear in the market in the very near future, but will require significant modification to cope with the denser, higher-value network of transmitters in Europe. The spectrum sensing approach is at an early stage of development and in isolation is unlikely to provide the level of protection required to prevent interference to broadcast services and radio microphones. However when this technique is combined with Geolocation techniques with EIRP control, the technology rapidly becomes viable. The potential opportunity of a new harmonized, licence-exempt band to support on-demand multi-media streaming in the home is an irresistible target and the technology is creating considerable interest.

INTRODUCTION

UHF terrestrial TV networks have historically been planned as Multi-Frequency Networks (MFNs) to support regional TV programming and to simplify international frequency co-ordination. This can be seen as a relatively inefficient use of the spectrum as a particular UHF channel carrying a TV multiplex for one region cannot be re-used until the signal strength has fallen to a level approaching the thermal noise floor. In the UK, 256MHz of spectrum is used to support 6 DTT multiplexes, each 8MHz wide. At any particular location, there will be a significant number of “empty” channels which cannot be used for additional high power TV services without causing interference to services in adjacent regions. Traditionally, these channels, known as UHF white space, have been used for low power applications in Programme Making and Special Events (PMSE), typically radio microphones and wireless in-ear monitors (IEMs). This usage is fairly sparse, however, and the possibility of using the white space for new, low-power, licence-exempt devices would provide an additional, much-needed band to supplement the popular but crowded 2.4GHz ISM band. This could potentially support high bandwidth wireless applications like multimedia streaming, video on demand and TV catch-up services which would be of particular interest to broadcasters.

WHITE SPACE ACCESS

Accessing the UHF white space for unlicensed applications has proved quite controversial, with existing licensees understandably nervous about the risk of interference to their services. Since the channel availability varies across the country, assigning white space allocations and access is not straightforward. To address interference concerns, two techniques are emerging for UHF white space access: spectrum sensing and geolocation.

Spectrum Sensing – “Cognitive Access”

The simplest access approach is to scan the TV spectrum for an unused channel and use this for the white space application on a “listen and broadcast when clear” basis. This is superficially very attractive: it requires no additional hardware or infrastructure as the white space device (WSD) can make use of the tuner and antenna needed for its own applications to carry out the initial spectrum scan.

Unfortunately the process is difficult and requires high performance RF circuitry and potentially complex signal processing as the

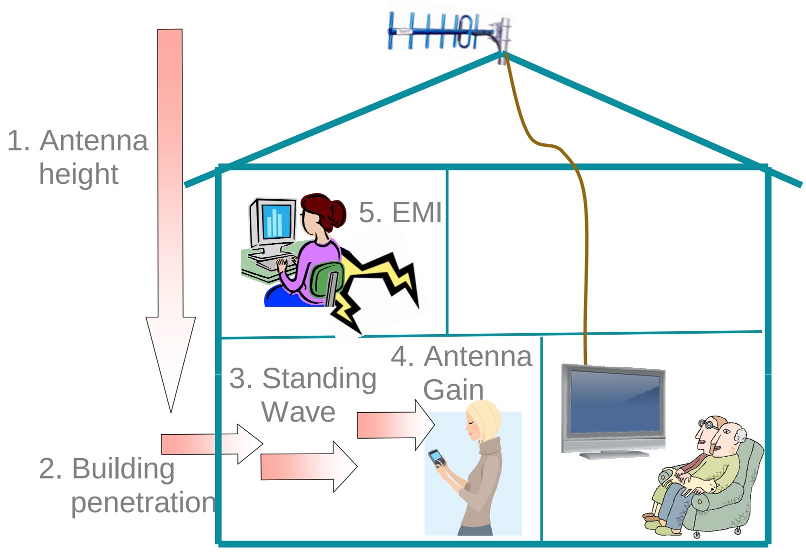

Figure 1 - Hidden Node Margin Loss Components

licensed DTT signal to be detected will be received at a very low level. The WSD will be lower in height than a normal DTT antenna, it will have a lower antenna gain and will have an obstructed view of the transmitter. These effects combine to give a hidden node margin; this hidden node margin relates the rooftop antenna signal level for DTT reception to the WSD signal level available for detection. The components of the hidden node margin are shown in Figure 1.

Research by Randhawa et al [1], suggests that for outdoor suburban deployments of WSDs in the UK, the hidden node margin will be as high as 40dB. This figure is based on outdoor sensing at 1.5m with a 0dBi antenna. Assuming a planned field-strength of 50dBμV/m at 10m, which would typically deliver –72dBm to a DTT set top box, the required detection sensitivity for a WSD would be –112dBm. For indoor deployment of WSDs, where building penetration and reflections further reduce signal level, the available signal strengths will typically be 20dB lower, suggesting an indoor hidden node margin of 60dB.

The difficulty of detecting such small signals can be appreciated by considering the signal-to-noise ratio available for sensing by the WSD. Using typical TV planning parameters taken from the Chester 97 DTT planning agreement [2], Table 1 shows how the available signal-to-noise ratio is degraded from the TV planning value by location, antenna gain and EMI effects. Detection of DTT signals buried in noise will be exceedingly difficult.

Required DTT CNR for QEF (64-QAM rate 2/3)		19 dB
Planning Margin		+ 8 dB
DTT antenna gain	12 dBi	
WSD Antenna gain	–10 dBi	
C/N loss at WSD antenna		–22 dB
Height loss	12 dB	
Building penetration loss	7 dB	
Indoor location variation (95%)	14 dB	
C/N losses due to location		–33 dB
Degradation due to EMI		–8 dB
S/N at WSD		–36 dB

Table 1- Carrier to Noise Ratio for DTT detection indoors at 1.5m

A number of prototype devices were assessed by the FCC in 2008 and the results of these tests by Jones et al [3] demonstrated detection of clean ATSC DTV signals at -116dBm in a 6MHz channel. This sensitivity is impressive, but unfortunately detection performance degraded significantly in the presence of high (–28dBm) and moderate (–53dBm) level signals in the adjacent and alternate channels. Some devices malfunctioned completely, whilst others were desensitized by up to 60dB, indicating device dynamic range limitations.

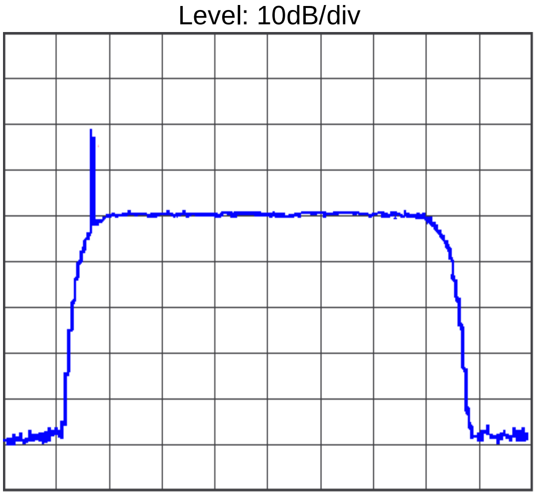

Figure 2 – ATSC DTV spectrum showing Pilot tone at -11.3dB

To achieve their sensitivity, the US

prototype devices have exploited the pilot tone in the ATSC DTV signal, which can be clearly seen on a spectrum analyser plot (Figure 2). For detection of DTV at -116dBm an overall signal to noise ratio of –13dB is available assuming a 3dB noise figure. However, by using a simple bandpass filter centred on the pilot tone, the signal to noise ratio improves significantly; for a 1kHz bandwidth filter, a signal to noise ratio of 13dB becomes available which is more than sufficient to rapidly detect the pilot.

Detection of COFDM systems like DVB-T and DVB-T2 will require far more sophisticated signal processing using correlation of the guard interval or detection of the OFDM pilot structure. This process is further complicated by the multiplicity of modes and has not yet been demonstrated on practical devices.

Geolocation

An alternative to sensing is to control access using an Internet-hosted, location-dependent database of available white space channels. A device would typically use GPS to locate itself and then request a table of available channels from a server. This avoids the difficulties associated with detection but clearly requires some additional hardware and infrastructure.

The technique is particularly appropriate for DTT protection, where channel assignments are essentially static but can readily be extended to protect PMSE use where access is licensed and logged by a band manager. This is particularly attractive in the UK where the existing PMSE band manager already makes extensive use of computer databases to license radio microphone users. In some countries PMSE is less well controlled and sensing techniques may still be necessary. PMSE sensing performance issues remain a concern and the FCC have chosen to adopt a “safe haven” approach reserving two location-dependent TV channels for exclusive PMSE use.

WSD EIRP LIMITS

Access to the white space channels using geolocation techniques should prevent co-channel interference, but careful control of the EIRP will be needed to prevent adjacent and non-adjacent channel interference. Ideally, devices will make use of power control to minimize interference and maximize opportunities for spectrum re-use. However sensible EIRP limits will be required to protect licensed incumbents and these must take account of typical antenna isolation values and the selectivity and overload characteristics of the existing receivers.

WSD to DTT Receiver Path Loss

The path loss between the WSD and the DTT receiver is clearly a crucial factor. Initial analysis by Ofcom [4] considered a WSD outdoors at 1.5m height, 45 degrees off axis to the DTT antenna as shown in Figure 3. The minimum distance between WSD and DTT antenna would be 10m, corresponding to a free space loss of 50dB at 800MHz. The WSD is off axis to the DTT antenna and was assumed to be 10dB down in gain from boresight, i.e. 2dBi, and the WSD antenna was assumed to be 2dB down from its peak value, i.e. –2dBi. For 800MHz operation, a feeder loss of 5dB was assumed, giving a total path loss of 50 +5 +2 –2 = 55dB.

Ofcom's initial analysis may slightly overestimate the path loss for some deployment scenarios however, for example at the lower end of the UHF band or for indoor use. This is of potential concern as the resulting WSD EIRP proposal might still cause interference to some DTT receiver installations. For example at 500MHz, a 2dB feeder loss would apply and the free space path loss would reduce to 46dB giving a total path loss and EIRP recommendation 7dB lower than the Ofcom figure.

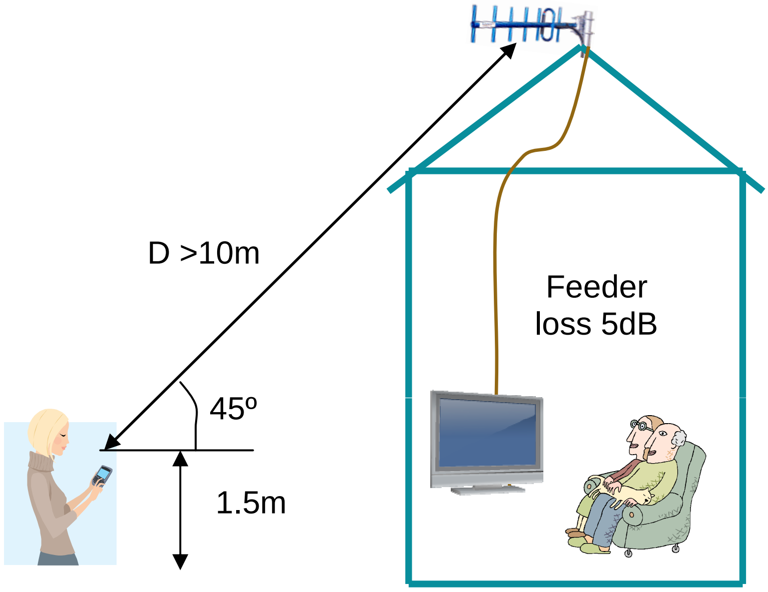

Figure 3 - Estimation of outdoor WSD to DTT receiver path loss

Indoor deployments are the most challenging and protecting portable receivers or DTT loft antenna installations may prove very difficult. Figure 4 shows a WSD access point in the loft space of a semidetached property. This could be less than 5m from a loft mounted DTT antenna in the adjacent property. Assuming a 7dB building penetration loss between buildings and on-axis coupling between the WSD and DTT antennas, the path loss at 500MHz would be 18dB lower than the Ofcom figure. This analysis is summarized in Table 2.

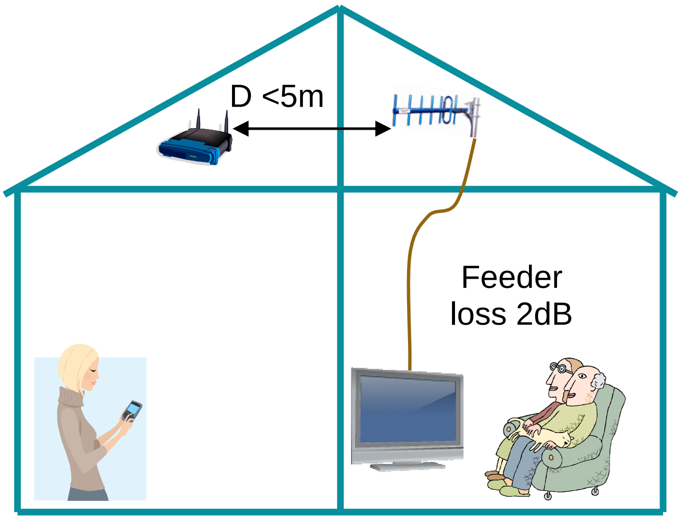

Figure 4 - WSD to DTT receiver path loss for loft installations

Scenario	1. Outdoor Band V	2. Outdoor Band IV	3. Adjacent Lofts
Geometry	Figure 3	Figure 3	Figure 4
Frequency	800 MHz	500 MHz	500 MHz
Distance (D)	10 m	10 m	5 m
Free Space Loss (l)	50 dB	46 dB	40 dB
DTT Antenna Gain (r)	2 dBi	2 dBi	12 dBi
WSD Antenna Gain (w)	–2dBi	–2 dBi	0 dBi
Feeder loss (f)	5 dB	2 dB	2 dB
Building penetration loss (b)	0 dB	0 dB	7 dB
Path loss (l–r–w+f+b)	55 dB	48 dB	37 dB

Table 2 – WSD to DTT receiver path loss scenarios

DTT Receiver Selectivity - C/I Performance

Receiver C/I performance is a measure of selectivity defining the permitted level of interference for a given signal level and frequency offset. Performance depends on the DTT mode and signal level and the interferer frequency offset. At low DTT signal levels the permitted interference level will be noise limited whilst at higher levels, non-linear effects become apparent and performance degrades again. For a typical receiver there is a region where the permitted C/I level is constant and this can be used for the EIRP limit calculations.

It is too early to characterize the actual interference rejection performance of DTT (or PMSE) receivers to WSD interference as the characteristics of the WSD signal are yet to be defined. An estimate of the likely performance can be made by assuming the WSD signal will be noise-like and similar to a DTT signal in its spectrum. The performance of real DTT receivers has been characterized in great detail and target specifications are published in the DTG-D book [5]. These performance targets are summarized in Table 3.

Test Condition (Offset)	Interference Level	C/I target (QEF)
ACI (N±1)	-25 dBm	-27 dB
Non ACI (N±2)	-25 dBm	-38 dB
Non ACI (N±3)	-25 dBm	-43 dB
Non ACI (N±M, M>4, M≠9)	-25 dBm	-47 dB
Non ACI (N+9)	-25 dBm	-31 dB
Linearity test (two interferers at N+2, N+4)	-25 dBm	-28 dB

Table 3 – DTT Receiver C/I targets

Estimate of WSD EIRP limit

By considering the minimum path loss between the WSD and the victim DTT receiver, the C/I performance of the receiver and the planned field-strength, the maximum permitted EIRP for the WSD can be estimated for different scenarios. In the UK, the country is split into 100m by 100m squares, or pixels, and the DTT field-strength is planned to exceed a mean value of 50dBμV/m, for 99.9% of these pixels. Assuming a DTT antenna gain of 12dBi, the received power can be calculated and is shown in Table 4.

Scenario	1. Outdoor Band V	2. Outdoor Band IV	3. Adjacent Lofts Band IV
Field-Strength at 10m (dBuV/m)	50	50	50
Antenna Gain (dBi)	12 dBi	12 dBi	12 dBi
Antenna Shielding (dB)	0 dB	0 dB	7 dB
Feeder Loss (dB)	5 dB	2 dB	2 dB
Received Power (dBm)	–78 dBm	–72 dBm	–79 dBm

Table 4 – DTT signal levels for outdoor and loft reception

Using the received power values from Table 4 and the DTG C/I targets in Table 3, the permitted WSD EIRP for each reception scenario can be predicted and is shown in Table 5.

Deployment Scenario	Test Condition (Frequency offset and receiver C/I)				
	Adjacent (N±1)	Alternate (N±2)	Non-Adjacent (N±M,M>4, M≠9)	Non-Adjacent (N=9)	Linearity limited (N+2, N+4)
	C/I =–27dB	C/I=–38dB	C/I=–43dB	C/I=–31dB	C/I=–28dB
1. Outdoor Band V	4 dBm	15 dBm	20 dBm	8 dBm	5 dBm
2. Outdoor Band IV	3 dBm	14 dBm	19 dBm	7 dBm	4 dBm
3. Adjacent Lofts Band IV	–15 dBm	–4 dBm	1 dBm	–11 dBm	–14 dBm

Table 5 – WSD EIRP limits

Note the EIRP limits are somewhat smaller than the values initially suggested by Ofcom (+20dBm non-adjacent, 13dBm adjacent) for a number of reasons. Ofcom have assumed receivers will outperform the DTG C/I performance targets by 7dB and have allowed an additional 3dB feeder loss in their Band IV analysis than that usually used for TV planning. Loft installations were not considered and may be very difficult to protect.

This analysis does not take account of location variations associated with the log-normal variation of field-strength within a planning pixel and this could reduce received power and EIRP still further. Furthermore, the use of domestic low noise amplifiers for signal distribution has not been considered and this can result in premature overload and degraded C/I performance.

CONCLUSIONS

Licence-exempt use of the UHF white space will become increasingly important as an alternative to the congested 2.4GHz ISM band for low-power, broadband and multimedia applications. The opportunity of an internationally harmonized, licence-exempt spectrum band is so attractive that the development of devices seems inevitable.

Cognitive spectrum sensing is attractive in principle, but the sensitivity, RF dynamic range and signal processing requirements are beyond that which can be reliably achieved with current technology. Requirements for outdoor sensing are difficult enough and indoor sensing looks virtually impossible. OFDM signals are far more difficult to detect than the ATSC signals so sensing may prove particularly impractical in countries using DVB-T and DVB-T2.

Geolocation is emerging as the preferred technique and WSDs will require GPS or similar location capability and Internet access to access the channel tables. This will prevent co-channel interference to incumbent PMSE and DTT, but adjacent channel interference remains a concern. Worst-case adjacent-channel inference analysis suggests that indoor DTT installations, including portable and loft mounted antennas, may be particularly vulnerable to interference.

To control adjacent channel interference it is desirable to extend the database to include EIRP values for each of the available white space channels. The EIRP will be a function of the level of the neighboring licensed services and the performance of the receiver. Locations at the edge of TV coverage will require lower EIRP limits than those enjoying increased coverage margins. Improved receiver performance may allow increased EIRP in the future. By including EIRP in the geolocation databases, device limits can evolve with time as understanding of the interference problems improves.

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