A Survey of TV White Space Measurements

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Summary. Unused spectrum in the television band (so-called TV white space) has the potential to provide new spectrum for access to information and communication services in developing countries. This claim has been subject to a variety of measurement studies. The purpose of this paper is to survey these studies to better characterize the spectrum that is provided by TV white space. We discuss some of the challenges to such studies and characterize the available TV white space spectrum in terms of the total volume that is available.

1 Introduction

The growing demand for wireless data transmission drives the search for alternatives to the current spectrum management schemes. In the long term, the only viable solution seems to be dynamic spectrum access once the technical details for its implementation are solved. In the near term, the use of currently vacant spectrum allocated to TV broadcast (so-called TV white spaces) can alleviate the spectrum crunch while opening the path for dynamic spectrum access. Several measurements campaigns have shown that the TV broadcasting spectrum is mostly unused in sparsely populated areas, especially in developing countries, as there is not enough return on investment for broadcasters to provide many simultaneous TV channels. For the same reasons, these are precisely the areas in which Internet access is frequently lacking.

TV White Spaces (TVWS) technology can take advantage of the improved propagation capabilities of these frequencies to provide affordable Internet access in rural areas. White spaces are also present in densely populated areas as a consequence of the transition from analog to digital TV, and these can be harnessed for wireless Internet access as well as other wireless communication services. The lower frequencies as compared with the ones used for WiFi (which in some places is becoming too crowded), are less attenuated by walls and offer an interesting alternative also for indoor Internet access, as well as for multimedia distribution. Finally, for machine to machine applications and the "Internet of Things" paradigm TVWS technology has significant advantages both for developed and developing economies.

A quest towards understanding the potential of TVWS has been initiated by way of experimental measurement campaigns that objectively strive to establish the nature and extent of spectrum usage and the resulting TVWS availability. These measurements vary based on factors such as their definition of occupied or not occupied, where they are made (e.g. outdoor vs. indoor) or the granularity of their occupancy metric. Though there is variation in the measurement techniques used and the precise occupancy metrics, these campaigns clearly assist to ascertain spectrum utilization and qualitatively understand current usage patterns. From the spectrum utilization or usage patterns it is feasible to ascertain the quantity of available white space spectrum. Furthermore, these measurements, since spectrum usage varies in time and space, provide a good opportunity to validate TVWS spectrum and channel models. These models provide a better understanding of current and projected spectrum usage that will allow devices to adaptively make more effective dynamic spectrum access decisions.

It is imperative that long term occupancy measurement campaigns and related analysis studies be carried out so as to ensure that government bodies, research and development agencies, and other interested parties target the real and evolving spectrum situation. However, in spite of the numerous active occupancy measurements in different parts of the world, there has been no comprehensive effort to date to analyze the different efforts that are scattered across the literature. Such efforts we believe should form the basis of informing better and more realistic spectrum occupancy expectations. As a step in this direction, the purpose of this paper is to survey spectrum occupancy measurement campaigns described in the literature.

We first discuss the basic measurement considerations from an occupancy perspective in Section 2. This is followed by a summary of survey outcomes in Section 3 which we subsequently discuss in Section 4. We conclude with Section 5.

2 Measurement considerations

To measure the available TVWS, there are two approaches. The first is to use a device to physically scan the airwaves to detect the presence of TV signals (the detector approach). The alternative is to use a database of known transmitters (the database approach). In either approach, the gathered information must be interpretted to define what is meant by "available" white space spectrum.

2.1 The detector approach

The detector approach uses the combination of a measurement device and a measurement plan. The measurement device can be a general purpose power detector such as a spectrum analyer or a detector specific to the type of signal. The ability to detect a signal depends on the characteristics of the detector. The sensitivity of the detecter determines how weak the signal can be and still get detected. There are fundamental limits to how weak a signal is detectable according to the noise floor, which depends on the measurement bandwidth, interfering signal present and detector noise figure. Higher quality detectors have lower noise figure and are thus able to discern weaker signals from noise. Signal specific filters and signal processing improve detection sensitivity.

The antenna configuration also plays a role.Higher gain antennas increase sensitivity but are more focussed in a narrower set of directions. The cable and connector losses between the antenna and the detector can also decrease detection performance. Setting detection thresholds in terms of field strength can remove some of this dependence on the antenna configuration. Even using field strength, it is still true that antennas mounted higher above the ground see less clutter and signal blockage than lower mounted antennas.

The measurement plan considers location, frequency, and time. For instance a device could move through a region seeking a specific TV signal. Or, it could seek out which TV signals are present across spectrum at a fixed location. Or, it might track the presence of a specific TV signal over time.

The primary challenge with the detector approach is the presence of detection errors where the detector either fails to detect the presence of a TV signal or gives false detections when no TV signal is present. The latter can be caused by noise and other signals. Or, atmospheric conditions can enable TV signals to be detected 100's of kilometers from their normal coverage area. A particular challenge comes once a white space is identified and then used by a secondary user. Subsequent measurements may see this as an occupied band and no longer identify it as white space. Because of these challenges, spectrum regulators advocate the database approach.

2.2 The database approach

This approach consists of accessing a database of known transmitters and their operational characteristics such as location, antenna parameters (radiation pattern, height above the ground), transmit power, times of operation and so on. From this database, topographic data, and potentially other data such as demographic data are used to predict what frequencies are available at different locations and times. Here the correct identification of the presence of a TV signal at a given location depends on the fidelity of the database information and the propagation model used to predict signal coverage. The primary challenge with the database approach is to find accurate information since in most countries spectrum usage information can be stored in many formats, electronic and paper, and the regulator has not collected these into a useful centralized database that is publicly available. Even when available, the approach is also computationally intensive if assessing a large region.

2.3 Characterizing available spectrum

There is a larger problem for both methods. Both methods focus on the transmitted primary signals. However, white space users must avoid interfering with the primary *receivers*. For example, an indoor detector antenna can fail to sense a TV signal that is nevertheless visible to a roof mounted receiving antenna, consequently allowing transmission in a channel that would cause interference to the incumbent. Conversely, a TV signal may be present and detected, but the intended secondary use is for a low-power indoor application that will not affect reception of stronger TV signals in other homes.

So, the results of both methods must be interpretted to yield a measure of the available white space spectrum. A detection threshold must be set. Measured (or calculated in the case of the database approach) primary transmitter signal strengths must be below this threshold value to declare a white space. Higher threshold values yield more white space while lower threshold values yield less. Generally, the threshold depends on the characterisitics of the primary service as well as the characteristics of the secondary user. For a lower power secondary service the threshold can be higher and vice versa.

Another concern are the frequency characteristics of the primary receiver and secondary transmitter. A primary receiver that does not have sharp front end filters or a secondary transmitter that spills into adjacent bands will require large guard bands on each side of the deteccted primary transmitters. Larger guard bands mean that less bandwidth will be available for white space users.

Given the detection threshold and the guardband, the measurement data can yield what frequencies are available at what locations and when. Availability can be considered in two ways, at the channel level and at the band level [5]. The former is associated with measurement of individual channels, either with the same or with different channel width and possibly spread over several different frequency bands to determine the fraction of these channels that are available. The latter strives for a measurement of a frequency band, specified by start and stop frequency, with a step width (or frequency resolution) that is usually smaller than the channel spacing, to determine the degree of occupancy over the whole band.

Measurements at either the channel or band level result in successive variable size blocks alternating between white space and primary user spectrum. A key metric to characterize the white space spectrum is the total white space bandwidth that is available at a given location. Broadband access favors a large block of spectrum more than many smaller blocks. So, another metric is the largest white space block size. The frequency distribution of the white space spectrum, whether mostly at lower frequencies or more at higher frequencies is also another characteristic. In this paper we focus on the total white space bandwidth that is available.

3 Paper survey results

This review paper focused on studies of white spaces in the UHF television broadcasting frequencies from 470 MHz to 862 MHz. Most studies considered a subset of this band in accordance with the local allocation of spectrum to the UHF TV band. The results obtained from these studies through the use of both geo-location databases and direct measurement via a detector are presented in Table 1. All of the results are outdoor measurements, except where noted otherwise.

Table 1. Total white spaces found by different studies in MHz

		No guard bands			**Guard bands**		
Type	Location	Urban	Urban Indoor	Rural	Urban	Rural	Year Published
1. Database	UK	$\approx$150			$\approx$30		2009 [13]
2. Database	Europe	176					2011 [15]
3. Database	Europe	$\approx$125			30		2012 [9]
4. Database	India	$\approx$112					2014 [12]
5. Detector	India	194		217			2013 [7]
6. Detector	China	168		32			2012 [17]
7. Detector	China	$\approx$232					2013 [16]
8. Detector	Hong Kong	$\approx$168	$\approx$235				2013 [18]
9. Detector	Philippines	304					2012 [14]
10. Detector	South Africa	$\approx$307					2013 [2]
11. Detector	Uganda	$\approx$208					2013 [6]
12. Detector	Vietnam	$\approx$141					2011 [1]
13. Detector	Italy	48	304				2014 [3]
14. Detector	Romania	168		262			2014 [10]

From the table, it is easy to see that there is a need to specify a number of factors under which a spectrum measurement attempt is made to give a clear picture of the actual TV white space available and its potential for use. How much TV white space is detected depends on these factors. For example, one needs to specify whether an attempt is made in an urban place or rural, outdoor or indoor, or whether guard bands are considered or not. The use of a particular frequency spectrum by wireless devices is affected by how contiguous it it. Consequently, it is also important to mention how much of the white space is contiguous to highlight its potential for use by white space devices. The results and some of the factors are discussed in detail in the next section.

4 Discussion

The studies from different countries reviewed in this paper have revealed that a significant amount of TV white space spectrum is available in the UHF band for utilization by secondary users; from 30 MHz to several 100 Mhz. The actual results differ from each other because every country is autonomous regarding local frequency allocation and is also bound by local regulatory bodies [4]. However, observations from these studies have shown that the typical total volume found is largely affected by a number of factors discussed here.

4.1 Conservative settings vs. relaxed settings

Studies have shown that when conservative settings as mandated by the US regulator, FCC are used, the amount of TV white space found is reduced. For example, Yin et al. [17] found no TV white spaces in all the locations they did their studies in China when they used a sensing sensitivity threshold of -114 dBm. However, relaying on the analog terrestrial television (ATT) database as ground-truth data for the ATT channel occupancy situation in Beijing, setting the sensitivity threshold to -97 dBm was enough to find white space ATT channels in indoor scenarios. Small variations in threshold values have also a very big impact on the amount of TV white spaces found. Lopez-Benitez et al. [8] reported that small variation in threshold value as low as 5 dBm or less, could change the spectrum occupancy observed from 100% to 0%. McHenry et al. [11] were able through careful measurements to determine detection threasholds that provided few missed detections with false alarm rates in the 20% to 60% range. These observations show that the signal detection threshold value is a critical parameter in deciding how much white space is detected. It highlights the importance of using an adequate criterion to select the decision threshold [8].

4.2 Indoor vs. outdoor

Another important observation noted from the studies is the difference in the amount of white space between indoor and outdoor scenarios. There is more white space in indoor scenario than outdoor scenario. For example, the study in Hong Kong [18], found that there were more indoor white spaces than the outdoor white spaces, which they associated with signal attenuation due to the blocking effects of walls. The blocking effect of walls was also found significative in [13], where it is reported that channels found occupied at the rooftop were almost always free in the basement thereby increasing the amount of white space available.

4.3 Rural vs. urban

Almost all the studies except one found that rural areas had more white spaces than urban areas, which is attributed to the greater number of TV broadcasting stations in urban areas with respect to rural areas. Kumar et al. [7] associated more white space spectrum in urban areas with the continuous fluctuation of TV signals as we move away from urban areas where TV transmitters are located to more remote rural areas. There is a sharp contrast between the findings by Yin et al. in [17] with the rest of the studies. They found more white spaces in urban areas than in rural areas. They did their study during the digital transition period in China, and they attributed their contrasting result to the lenghty transition time of the migration process from analogue terrestrial television (ATT) to digital terrestrial television (DTT), resulting in concurrent broadcasting of ATT and DTT in rural areas. All in all, the exact number and frequency composition of TVWS vary from location to location and is determined by the spatial arrangement of TV transmitters and their nationwide frequency allocation planning [13].

4.4 Regional variations

Very few studies have focused on studying regional variations, out of the thirty plus studies analyzed, only one dealt with regional variations. Van de Beek et al. [15] studied the availability of TV white space in some European countries, and when compared with the US, they found that their results show that at an average location in a representative European region, about 56% of the spectrum is unused by TV networks, compared to the 79% in the USA. They concluded that their results confirm quantitatively the often-stated expectation that there are fewer white spaces available in Europe compared to the United States of America. In general, developed regions have have less white spaces than developing regions largely due to the differences in the number of TV broadcasting stations. Even in Urban areas, the average amount of TVWS spectrum in developing countries is about 200 MHz.

5 Conclusion

From the papers analyzed, we can conclude that there is a great potential for leveraging white space frequencies to provide badly needed two way telecommunication services in rural areas, especially in developing countries where white spaces are abundant and telecommunications infrastructure is lacking. In developed countries, indoor white spaces can better be harnessed for wireless sensor applications like electrical power meters and for indoor content distribution to address congestion in the 2.4 and 5 GHz unlicensed bands. A combination of database consultation and spectrum sensing could provide a more accurate assesment of channel occupancy, leading to a more efficient spectrum usage while protecting incumbents from interference. The establishment of the power level threshold to decide spectrum occupancy is very critical, and further studies are warranted to refine its choice. Other occupancy detection methods relying not in the power but on the statiscal properties of the incumbent signals could prove useful in the future as the required signal processing becomes more affordable.

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