# White Space Regulation and Opportunities

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***Abstract*— Spectrum inefficient exploitation reported by several measurement campaigns demands introduction of new spectrum management strategies. Dynamic spectrum access techniques are appointed as one of the new mechanisms that should be included in the new spectrum management strategy. In this paper we defend the introduction of hierarchical dynamic spectrum access methods which differentiate primary/incumbent and secondary spectrum access rights. Unlicensed secondary users should be able to access spectrum not used in a given location at a given time – white spaces. We describe the three methods that secondary devices may use for gathering surrounding radio context information and obtaining adequate operating parameters. Finally we enunciate some applications that could be developed in the white spaces.**

***Index Terms*— Dynamic spectrum access, measurement campaigns, spectrum management, white spaces.**

## I. Introduction

Nowadays the common user can benefit from a wide portfolio of wireless applications supported by different sized wireless networks, adopting different air interfaces which were designed to comply with different requirements. However they all share the need to use spectrum.

Technologies as mobile broadband and WLAN are attracting an enormous number of subscribers. In addition, the introduction of powerful portable devices such as smartphones and tablets are making possible the introduction of appealing data services. As a result, wireless data traffic is increasing year-on-year, and such trend is expected to continue in the next years. Therefore, the spectrum bands allocated to these technologies are starting to be congested, and more spectrum seems to be allocated in a near future.

However, measurement campaigns performed up to now show that in densely populated urban areas, on average, less than 20% of the frequency bands below 3GHz are used during a working day. In less populated or rural areas the spectrum occupancy is even lower [1-3].

The results of several measurement campaigns [1-9] are summarized in Table I. Although these results cannot be directly comparable, as the measurement setup and methodology adopted were not the same (e.g. frequency span, frequency bin length, spectrum analyzer's resolution bandwidth, detection threshold), some obvious conclusions can be immediately drawn by inspection of Table I: in some time of the day, at some locations, very frequencies are not being used. As expected, spectrum occupancy is lower in less populated areas than in dense populated areas, and in indoor environments than in outdoor environments.

TABLE I
Spectrum Occupancy Measurement Campaigns

| Location(s) | Year | Measurement Frequency Range | Average indoor occupancy | Average outdoor occupancy | Ref. |
|---|---|---|---|---|---|
| 7 locations (USA) | 2004 2005 | 30MHz-3GHz | N/A | 5.2% NY:13.1% Chic:17.4% | [1-3] |
| Auckland (New Zealand) | 2006 | 806MHz-2.75GHz | 5,72% | 6,21% | [4] |
| Aachen (Germany) | 2007 | 20MHz-3GHz | 32% | Near 100%[a] | [5] |
| Singapore | 2007 | 80MHZ-5.85GHz | N/A | 4,54%[b] | [7] |
| Barcelona (Spain) | 2008 | 75MHz -3GHz | N/A | 22,57%[c] | [8] |

[a] This value is clearly overestimated, because the detection threshold (less than 112dBm) was very low, so the energy detector cannot distinguish out-of-band and man-made noise from primary users' signals. In [6] higher threshold value was applied (-107dBm) to the same measurements, resulting in lower spectrum occupancy values (see Table3 of [6]).

[b] This study uses different approach for determining the "noise floor": for each 60MHz sub-band, it considers the "noise floor" as the minimum power level observed in that band during all measurement campaign. The detection threshold was 6dB above such "noise floor". This could lead to an excessively high detection threshold. The authors of [5] did not detect activity in 3G uplink and 2.4/5GHz ISM bands, which suggests the threshold used in these bands is indeed too high.

[c] According to [8][9] the spectrum occupancy statistics obtained in this study should be interpreted as upper bounds of the actual spectrum occupancy, because the considered frequency bins were larger than the signal bandwidths of several bands. Therefore, the results are overestimated.

The unused frequencies in a given instant in a given place are known as white spaces, and their existence is the evidence that much of the spectrum is not being used efficiently.

It must be stressed that in majority of the measurement campaigns, the most occupied bands were the TV broadcasting bands and the 2G mobile cellular bands. However these campaigns were performed in a moment when analogue and digital TV emissions coexisted. Meanwhile the analogue transmissions are being switched off, which we expect, would reduce the TV broadcasting bands occupancy.

The remaining of this paper is organized as follows: in Section II some comments on the measurement setup dimensioning are made, in Section III the spectrum

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management models are described, finally Section IV appoints some suggestions on changes to current spectrum management model which would allow using the white spaces.

## II. Measurement Setup Considerations

According to [9] measurement equipment should be carefully dimensioned in order to be able to detect both narrow and wideband signals, with powers going from near the noise floor up to high values capable of overloading the receiver equipment. So the measurement setup must include appropriate filters to remove either extremely in-band strong signals or undesired out-of-band signals. In addition, low noise amplifiers should be inserted near the antenna to improve the equipment sensivity. A suitable measurement setup would include:

a) If the frequency span to measure is narrow, one antenna should be sufficient. However, if the frequency span is some GHz wide, it should be divided in sub-bands, and an appropriate antenna for each band should be selected. Omnidirectional antennas with vertical polarization could make easier the measurement tasks.

b) Appropriate filters should be included to remove either extremely strong in-band signals or the undesired out-of-band signals coming from each antenna. This could avoid overloading the receiver and limits the amount of noise received.

c) A low noise amplifier near the antennas may be necessary to improve the sensivity of the measurement equipment.

d) The *frequency bins* should be narrower than the signals expected to be detected. So it would be desirable to divide the overall frequency span in several sub-bands, and adjust conveniently the frequency bin size for each sub-band. Remember that if the frequency bin size is larger than the bandwidth of the signal we want to detect, the spectrum occupancy results will be overestimated.

e) The spectrum analyzer's *resolution bandwidth* must also be adequately adjusted for each sub-band according to the signals bandwidths' expected to be detected. Decreasing the resolution bandwidth will lower the noise floor and increase the ability to detect weak signals. However the time consumed to perform the measurements would increase.

f) Time duration of the measurement campaign should be set according to the measurement objectives: if what is intended is a realistic average value of the spectrum usage, then the longest the campaign the better. However, if we are interested in the variation of spectrum use in certain period of day, then the measures could be taken only at those periods.

g) The pos-processing of the measured data consists in classifying the frequencies as used or unused. Most of the measurements use the *energy detection* algorithm to perform such classification. According to this algorithm, the energy of the received signal with a given frequency is compared with a *detection threshold*. If the energy is above the threshold, then that frequency is occupied, otherwise the frequency is unoccupied.

Choosing *high detection thresholds* may underestimate the ability to detect weak signals (e.g. signals experiencing deep fading in that instant). On the other hand, *excessively low detection thresholds* would overestimate the spectrum occupancy, as out-of-band interference and man-made noise would be confused with primary users' signals. So, for each measurement setup, location and primary user's signal, an appropriate threshold level should be identified, in order primary user's signals could be identified even if experiencing fading and/or interference. The most common approaches for setting the appropriate threshold consist in substitute the antenna with a matched load and measure the noise statistics (max, min, average, variance) at each frequency and afterwards select the threshold using one of the following criteria [9]:

i. *Maximum noise criterion:* Threshold(*f*) = maximum noise sample measured at frequency *f*. Using this criterion the spectrum occupancy in never over estimated, but can be underestimated.

ii. *X-dB above criterion*: Threshold(*f*) = X dB above mean noise value at frequency *f*. Values of X=3dB, 6dB and 10 dB (ITU) are usually considered. The problem with this criterion is that, as the noise statistics may vary with frequency, a constant value of X over the whole frequency range causes the over or underestimation spectrum occupancy error to vary through the frequency range.

iii. *Probability of false alarm criterion*: Threshold(*f*) = value calculated for frequency *f* in a way that only a fraction of the measured noise samples noise are allowed to lie above that threshold. That fraction of noise samples above the threshold constitute the Probability of False Alarm (PFA) that the system can accommodate. So, using this criterion, the spectrum occupancy is overestimated at most by the PFA for every frequency.

As an additional criterion proposal, we think it makes sense to adjust the detection threshold to the sensivity levels defined in the standards of each wireless technology being measured.

## III. Spectrum Management models

Since the early day of wireless technologies until now, the access to spectrum is managed locally by the National Regulation Administration (NRA) using exclusively the "*command and control*" strategy. Under this methodology, the regulator decides which band should be allocated to each technology and service in order to get the maximum benefits for the national citizens during a given period of time. Some of the bands are licensed for exclusive use by one telecom operator (e.g. mobile broadband bands), while others are allowed to be used simultaneously by several license-exempt individual users (e.g. Industrial Scientific and Medical – ISM – bands). In this model, the licenses are usually granted through *"beauty contests"*.

In alternative to the *"command and control"* strategy, the *"spectrum market"* and *"free commons"* solutions can also be used.

In the case of the *"spectrum market"*, the NRA can try to assure that the spectrum is used for a given service, but the final decision is market driven. Under this model, telecom operators are granted licenses to use the spectrum through *auctions*. By allowing spectrum trading among telecom players, this solution may evolve to a complete liberalized spectrum secondary market (as in U.S.A. hosted by Spectrum Bridge since Sept. 2010). If this is to occur, primary or secondary access rights to the spectrum owned by an operator could be traded with other operator through the payment of the corresponding fee.

Finally, *"spectrum commons"* defend the free use of spectrum – a public resource – by anyone. In this model, there is no license to be granted. Every user can access the spectrum as long as this is physically possible.

Although truly *"command and control"* solution is causing very inefficient use of some spectrum bands, the other models have also inconvenients.

In what concern's the market driven approach, it can lead to operators applying for NRA licenses with the only intention of selling their rights to another operator. If the spectrum price is too high, there may be no interested parties in buying such spectrum rights, and in this case we will assist to completely unused bands. Even if there are interested parties, they may only be able to buy access rights to narrow spectrum bands, which will lead to a very fragmented spectrum use.

The free access to spectrum through "free commons" approach is not optimal also. In this approach the access to spectrum would be allowed to anyone, using any technology in an uncoordinated fashion. Therefore, if the number of users in a given area is reasonable, this uncoordinated operation will lead to excessive interference levels that would turn communications impossible.

In the following section we propose an alternative to current *"command and control"* spectrum management strategy while avoiding the other strategies drawbacks.

## IV. DYNAMIC SPECTRUM ACCESS (DSA)

We think the use of dynamic spectrum access (DSA) techniques would increase the efficiency of the current *"command and control"* spectrum management model. Therefore we defend the dynamic assignment of spectrum to any wireless technology, using a hierarchical approach. Under this approach, primary and secondary spectrum access rights are defined. The primary users will be granted a licensed by the NRA to use a given band. Therefore they have priority accessing the spectrum. However, when licensed primary users are not using the spectrum, unlicensed secondary users should be able to use it, in a non-protected and non-interfering way. As such, secondary users must be able to detect the unused frequencies, must be capable of transmitting on those frequencies without interfering with primary users in the neighborhoods, and must stop using the frequency as the primary users needs it again.

This is a complex task, which can be addressed by software defined radio (SDR) and cognitive radio (CR) technologies.

However, such technologies, especially CR, are at their infancy, and as such, secondary user devices using CR technology should start being introduced in less demanding scenarios.

One of the less demanding scenarios is the use of TV white spaces. In such bands, the primary users activity can be easily predicted, as TV broadcasting stations are fixed, their location and operational parameters are known.

We stated that measurement campaigns determined TV bands were one of the most occupied ones. However the recent migration to digital TV (DTV) and the shutdown of the analogue transmissions should free a reasonable amount of spectrum in VHF and UHF bands.

To use TV white spaces, secondary devices should acquire knowledge of primary users activity in the place they are located. Three solutions emerge as possible: a) perform spectrum sensing; b) make use of geolocation followed by access to a primary user protection database; c) use radio beacons.

Spectrum sensing has the most desirable properties, as the secondary device would be completely autonomous. However, to avoid the hidden-node problem, current spectrum sensing algorithms need to detect extremely low power levels. As already mentioned in the Section concerning the spectrum occupancy measurement campaigns (Section II), such low threshold values may turn primary users detection impossible in some occasions due to out-of-band emissions of other devices and man-made noise.

Radio beacons consists in broadcast over a given region the available frequencies in that region. This would require the development of a costly new cellular infrastructure, or the sharing of the existing ones. Neither solution seems feasible in the near future.

We think the geolocation plus database access is the most advantageous solution for the moment. In this solution, the secondary device would communicate its location, bandwidth need, expected duration of communication, etc to the database. The database would then answer back, reporting the available frequencies, corresponding maximum allowed e.i.r.p., time validity of such allocation, etc.

This method would allow making a more efficient use of spectrum while protecting primary users operation. Additionally, it would turn easier the job of NRA issuing temporary licenses, as the only thing necessary is to mark in the database the required frequencies as used.

Due to UHF propagation characteristics, TV white space devices would experiment a three fold increase on coverage range compared to 2.4GHz ISM devices for the same transmitted power. This characteristic would make them appropriate for applications such as:

- Extended broadband coverage using less access points

(university campus, hospitals, rural communities, etc);
- Remote meter applications;
- Urban transportation applications (spread information about waiting times on bus/train waiting stops)
- Urban publicity (send publicity for screens spread around a city)
- Monitoring of energy infrastructure (e.g. wind farms)
- Extended range walkie-talkies
- Extended capacity for cellular networks during peak hours.

Many more applications may exist. The limit is the imagination.

Most of these applications possess reasonable economic added value, or bring benefits for the citizens. As such, we defend that TV white spaces exploitation should be made possible as soon as possible.

We are confident that the results provided by TV white space systems will increase the confidence to allow the use of white spaces in other less used bands.

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