GSM Downlink Spectrum Occupancy Modeling

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***Abstract*—In this article the spectrum occupancy of a GSM900 and a DCS1800 band as an analog power or binary quantized power is modeled. In the case of analog power it is presented histograms of the power distribution during one working day. In the case of quantized power it presents the two time statistics, the time period of opportunities distribution and the time between opportunities distribution. The measurement setup is standing in line of sight with the base station. Also, the measurement setup in terms of maximum sensitivity is described and analyzed. Spectrum non occupancy, for a working day, in terms of total time for the GSM900 band and for the DCS1800 band is given.**

***Index Terms*—Cognitive Radio, Spectrum Occupancy Models, Measurement Setup**

I. Introduction

Cognitive Radio Systems will be used in order to maximize the full potential of the allocated to and unutilized spectrum of primary systems. The study of the technology associated to these systems are in an initial stage despite of several years of evolution and one standard already set (IEEE 802.22, for packet use in rural areas using the holes of TV spectrum).

The Power Spectral Statistics must be characterized in order to find channel occupational models. Each sample of these occupational models functions could be analog or quantized. The quantized model could be associated to one (two levels) or more thresholds depending of the resolution necessary to it description. These models could be used in the study of sensor fusion in secondary networks. In this article the analog and quantized (one threshold) occupational model for GSM900 and DCS1800 in a standing line of sight reception scenario is described and analyzed. The analog occupational model is presented by the histograms (distribution) of the powers levels during one day for one GSM900 band and one DCS1800 band. The binary quantized model is presented by the time between opportunities distribution and the time period of opportunities distribution.

The measurements are described in the Portuguese frequency allocation context. This work complements the one presented in [1] which presents the period of time of opportunities distribution for a GSM900 band in a mobile situation. This work goes beyond other spectrum occupational articles [2]–[6] in the way that it tries to model the spectrum occupancy.

Also, it presents and mathematically analyzes the measurement setup used. Spectrum non occupancy, for a working day, in terms of total time for a GSM900 band and a for DCS1800 band is presented.

The Section II describes the Measurement Setup. In Section III the best sensitivity achievable by the measurement setup is determined. In Section IV, the measurements and correspondent statistics and distributions are presented. And finally in Section V, the main conclusions are stated.

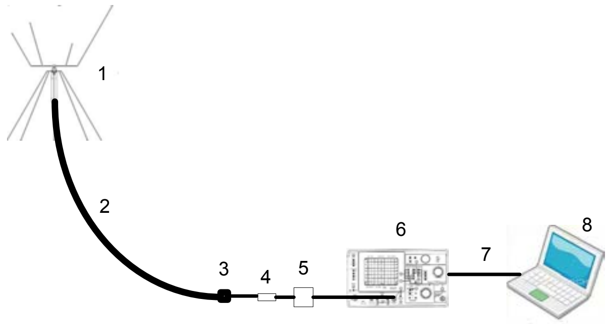

Figure 1. Measurement Setup, 1 - M-POL Antenna, 2 - Low Attenuation Cable, 3 - N-SMA Adapter, 4 - Filter, 5 - Pre-Amplifier, 6 - Spectrum Analyser, 7 - Ethernet LAN Cable, 8 - Portable Computer

II. Setup Description

The measurement setup is pictured in Figure 1. It is composed of a high bandwidth omnidirectional antenna ($25MHz-6GHz$) from MP Antenna with typical $3dBi$ gain. A semi-rigid low attenuation cable (typical < 0.12 dB/meter at $5GHz$) with about 8 meters, a high steeply passband filter ($500MHz - 1GHz$ for GSM900, $1GHz - 2GHz$ for DCS1800), a high bandwidth preamplifier ($15dB$ gain at $950MHz$), a Spectrum Analyser (SA) and a Portable Computer with an Acquisition Program. From the low attenuation cable, to the SA, the components are connected with thin cable with SMA connectors. The preamplifier gain is such that the GSM signal ($-102dBm$ in $200KHz$, sensitivity level) is brought above the noise level of the SA but not enough to generate visible intermodulation products due to non linearity of the input mixer of the SA. The SA is set in the highest sensitivity *i.e.* with $0dB$ attenuation of the input attenuator. The total signal in $500MHz - 1GHz$ band (pass band of the filter) at the input of the SA was about $-17dBm$. The secure signal level in terms of intermodulation is below $-10dBm$. Another criterion in choosing the filter is: that the higher passband frequency is not more than one octave from the lower passband frequency. This avoids the second order intermodulation products to be inside the passband.

The measurements took place at the top roof of the Department of Electronics, Telecommunications and Informatics of the University of Aveiro as shown in Figure 2.

III. Setup Analysis

Figure 3 shows the equivalent circuit of the measurement setup from the preamplifier to inside the Spectrum Analyzer (SA) including the sum of the internal noise. S_i is the input

Figure 2. Antenna deployment

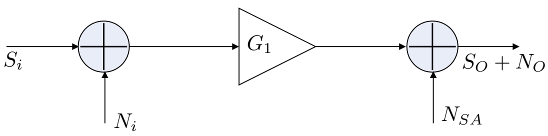

Figure 3. Equivalent circuit of the measurement setup from the preamplifier to the inside of the Spectrum Analyzer

signal, N_i is the noise signal at the input. These two signals are already combined before the preamplifier, despite showing the combination at the input. $\mathbf{G_1}$ is the Power Gain of the preamplifier, N_{SA} is the internal noise signal of the SA, S_0 is the output signal resulting from S_i, and N_0 is the output noise signal. Also, there is one variable, the noise figure of the preamplifier $\mathbf{NF}$, which is not shown. The power of the signals described previously is represented with the same letters of the signals, but in boldface. The power of these signals is measured in logarithm form (dBm/Hz), and the noise figure $\mathbf{NF}$, as well as the gain $\mathbf{G_1}$ in dB. $\mathbf{N_i}$ depends on the environment noise caught by the antenna and the noise added by the lossy elements before the preamplifier. $\mathbf{S_i}$ is the power of the signal caught by the antenna at the measured frequency, attenuated by the lossy elements before the preamplifier.

How much $\mathbf{S_i}$ must be above $\mathbf{N_i}$ in dB (or the signal to noise relation in linear) in function of the gain $\mathbf{G_1}$, considering the limit case of $\mathbf{S_0} = \mathbf{N_0}$ is then calculated. This last condition limits the point which can separate signal from noise. The minimum of that function could be described by Equation 1

$$\begin{cases} \left\{\widehat{\mathbf{G_1}}\right\} = \arg\min_{\{\mathbf{G_1}\}} \left[\mathbf{S_i} - \mathbf{N_i}\right] \\ \mathbf{S_0} = \mathbf{N_0} \\ \mathbf{S_0} = \mathbf{S_i} + \mathbf{G_1} \\ \mathbf{N_0} = 10\log\left(10^{(\mathbf{N_i}+\mathbf{NF}+\mathbf{G_1})/10} + 10^{\mathbf{N_{SA}}/10}\right) \end{cases} \quad (1)$$

$\mathbf{S_i}$ is given by

$$\mathbf{S_i} = -\mathbf{G_1} + 10\log\left(10^{(\mathbf{N_i}+\mathbf{NF}+\mathbf{G_1})/10} + 10^{\mathbf{N_{SA}}/10}\right) \quad (2)$$

Considering $\mathbf{N_i} = -174dBm/Hz$ (best case), $\mathbf{NF} = 3.5dB$ and constant with the preamplifier gain, $\mathbf{N_{SA}} = -155dBm/Hz$, then the Figure 4 presents $\mathbf{S_i} - \mathbf{N_i} = f(\mathbf{G_1})$. Looking at Figure 4, it is concluded that the solution of Equation 1 for $\mathbf{G_1}$ is infinity. And the value reached at infinity for $\mathbf{S_i} - \mathbf{N_i}$ is $\mathbf{NF}$ (by the limit of Equation 2 minus $\mathbf{N_i}$ in both sides with $\mathbf{G_1}$ to infinity).

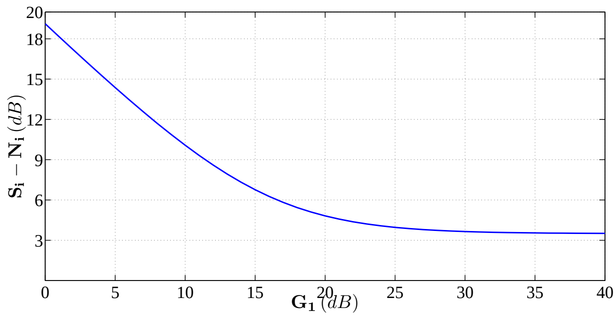

Figure 4. $\mathbf{S_i} - \mathbf{N_i}$ in function of $\mathbf{G_1}$

The lossy elements before the amplifier will be taken into account in order to calculate the minimum GSM signal that can be detected with this setup. The antenna gain is also taken into account. The lossy elements mentioned above, will amplify (or add in dB) the noise induced by the antenna. This amplification is equal to the attenuation induced to the signal (Cable attenuation times Filter Attenuation - plus if in dB). This attenuation amount in dB, is represented by $\boldsymbol{\alpha_{dB}}$. The Figure 5 represents the operations made to the signal and to the noise from the antenna to the preamplifier input. In an ideal scenario the noise at the antenna output will be the thermal noise (N_{th}) and equal to $-174dBm/Hz$ ($10^{\mathbf{N_{env}}/10} = 0$, environmental noise power equal zero). Considering a gain $\mathbf{G_1}$ equal to infinity and that the antenna catches the lowest detectable power. Then

$$\begin{cases} \mathbf{S_i} - \mathbf{N_i} = \mathbf{NF} \\ \mathbf{N_i} = -174dBm/Hz + \boldsymbol{\alpha_{dB}} \\ \mathbf{S_i} = \mathbf{S_{A\,in}} + \mathbf{G_A} - \boldsymbol{\alpha_{dB}} \end{cases} \quad (3)$$

which is equivalent to

$$\mathbf{S_{A\,in}} = -\mathbf{G_A} + 2\boldsymbol{\alpha_{dB}} - 174dBm/Hz + \mathbf{NF} \quad (4)$$

It was considered the attenuation of the cable connecting the antenna, plus the pass band filter attenuation to be $\boldsymbol{\alpha_{dB}} = 1.5dB$. The antenna gain is $3dBi$ and considering the noise figure $3.5dB$, then $\mathbf{S_{A\,in}} = -170.5dBm/Hz$ or

$\mathbf{S_{Ain}} = -117.5dBm/(200KHz)$. This is the lowest GSM signal detectable with this setup.

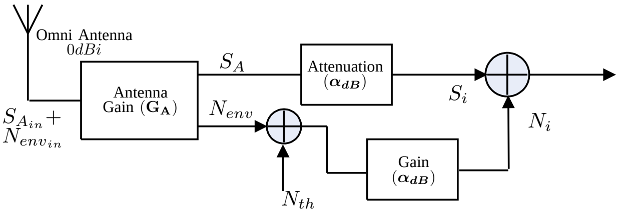

Figure 5. Equivalent circuit of the measurement setup from antenna to preamplifier input

IV. Measurements and Statistics

The measures were taken at a distance of 250 meters (measured with GPS) from the nearest GSM base station during school period. This base station covers, the University Campus with a population of approximately 15000 students, using GSM900 and DCS1800 bands. Two GSM operators are co-located in this base station belonging the studied GSM900 band to one operator and the studied DCS1800 band to the other.

The measurements were done with a resolution bandwidth of $100KHz$ at 501 points covering in excess all GSM900 downlink band (Figure 6) and the allocated part of the DCS1800 band (Figure 8). Each measured $100KHz$ covers one side of the $200KHz$ GSM band. In the case of single frequency, the 501 points were measured in a specific frequency with a span equal to zero. The measured power was adjusted to reflect the power received at the output of the equivalent unit gain antenna (see Figure 5, at output of the Omni-Antenna) and for the bandwidth of 200KHz it was added 3dB. The time at each measurement point was set to the frame period (about $4.62ms$) giving a sweep time about $2.4s$. There is practically no delay between consecutive measurements.

Figure 6 shows the spectrum occupancy of GSM900 band at 5H19 of a working day. The frequency axes ticks are the limits of the bands of the three Portuguese GSM operators. Figure 7 shows the spectrum occupancy of GSM900 band at 13H in the same 24H. The City of Aveiro is a plane region and because of that the antenna is at line of sight of several base stations, hence the high occupancy. In that situation two base stations with a decade of distance (in relation to the setup antenna) one from another could originate a diference (in dB) on the received power as low as $20dB$ (assuming that the same power is being transmitted). The power measurements done for this sectorized base station shows that the power received from the other sectors, is not more than 20dB below (measured in the Broadcast Control Channels (BCCH) which has no frequency hopping).

Figure 8 shows the spectrum occupancy of the DCS1800 band at 5H19 of a working day. The Portuguese Communications Regulator (ANACOM) allocates spectrum according to the operators needs and requirements. For this reason, there are two bands for each of two operators and a larger band for one operator only. Figure 9 shows the spectrum occupancy of the DCS1800 band at 13H in the same 24H.

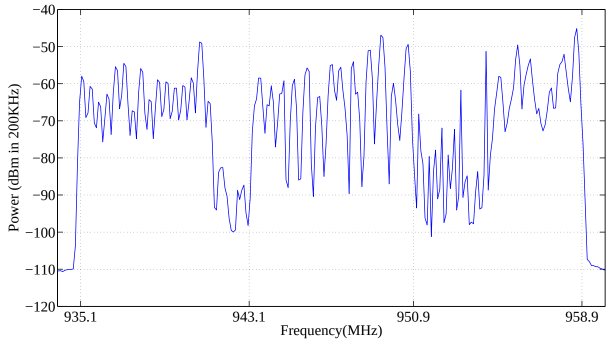

Figure 6. Typical Power Spectrum Density at 5H19 for GSM900

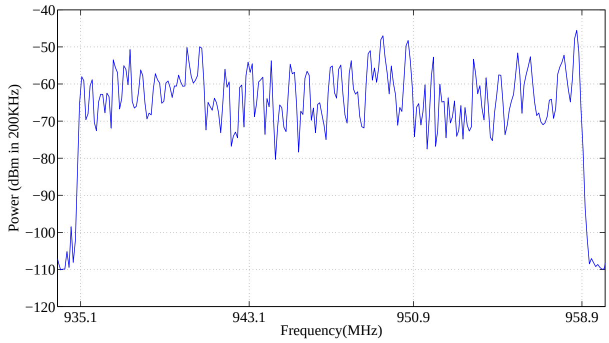

Figure 7. Typical Power Spectrum Density at 13H for GSM900

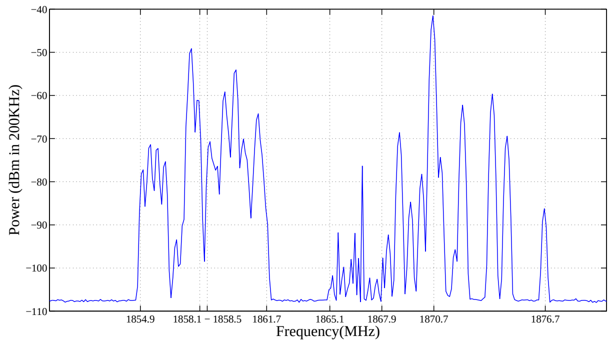

Figure 8. Typical Power Spectrum Density at 5H19 for DCS1800

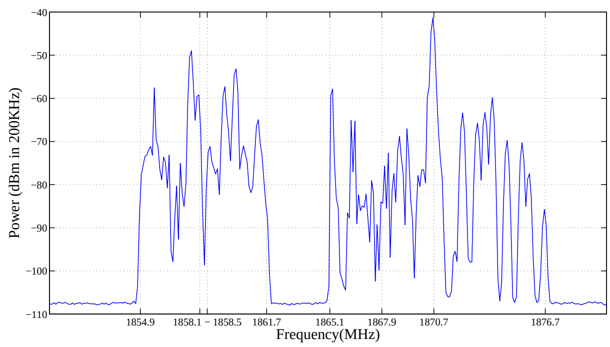

Figure 9. Typical Power Spectrum Density at 13H for DCS1800

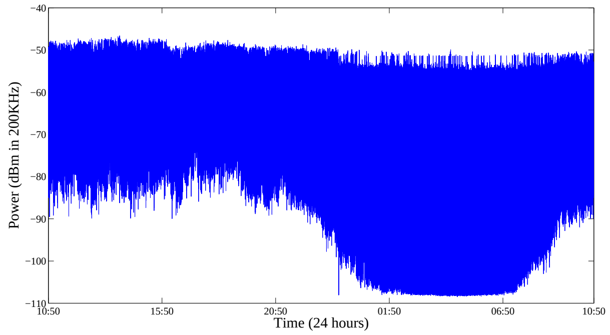

Figure 10. Power in the $953.9 - 954.1MHz$ band during one day

Measurements were made during four consecutive working days and the power profile was similar between days. Figure 10 presents the power variation at the $953.9 - 954.1MHz$ band in one of the four days measured. The correspondent power occurrence is presented in Figure 11.

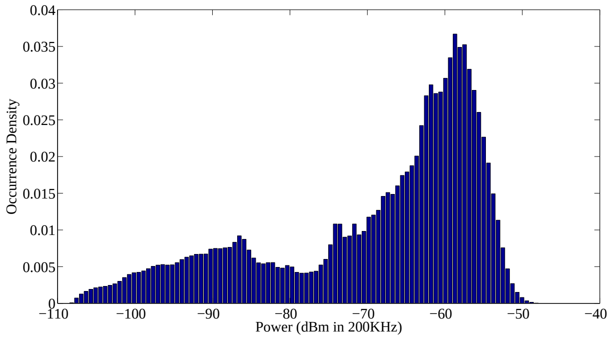

Figure 11. Power Occurrence Density in the $953.9 - 954.1MHz$ band during one day

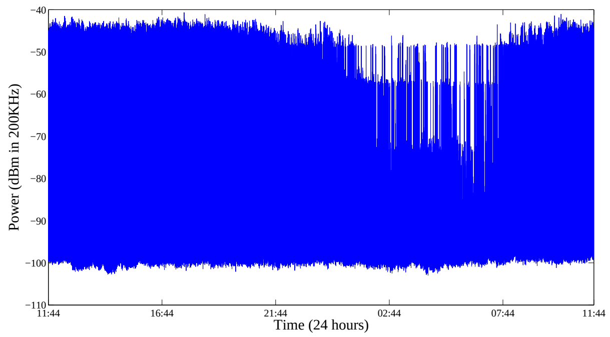

Figure 12. Power in the $1856.9 - 1857.1MHz$ band during one day

In Figure 12 is presented the power variation during a working day in the band of $1856.9 - 1857.1MHz$. The correspondent histogram is presented Figure 13.

For the time statistics a threshold must be defined. The threshold was set approximately $10dB$ above the noise level, just a few dBs below the minimum level needed to detect the signal with an adequate error probability. The decision level for GSM900 was $-98dBm/200KHz$ and $-90dBm/200KHz$ for DCS1800.

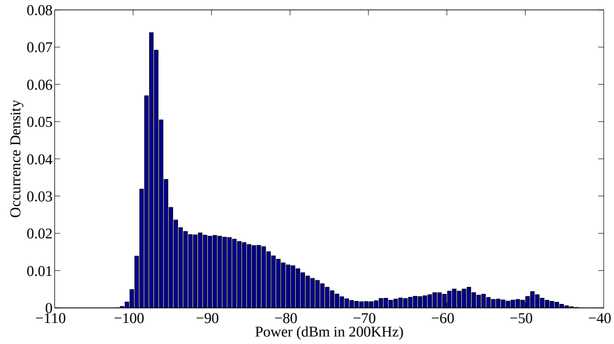

Figure 13. Power Occurrence Density in the $1856.9 - 1857.1MHz$ band during one day

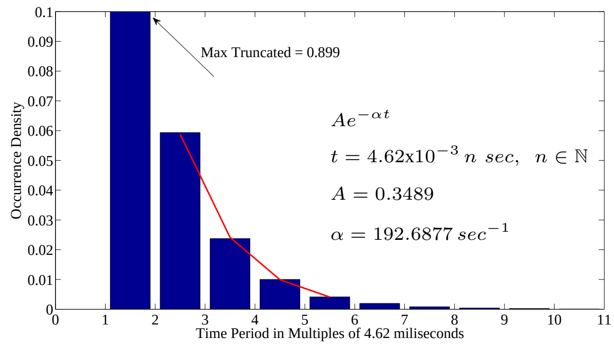

Figure 14. Time period of opportunities distribution of the measured GSM900 band

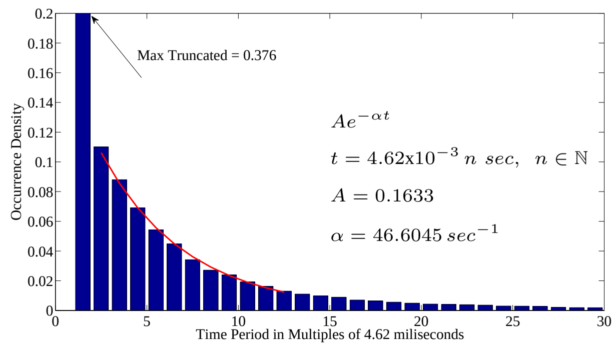

Figure 15. Time between opportunities distribution of the measured GSM900 band

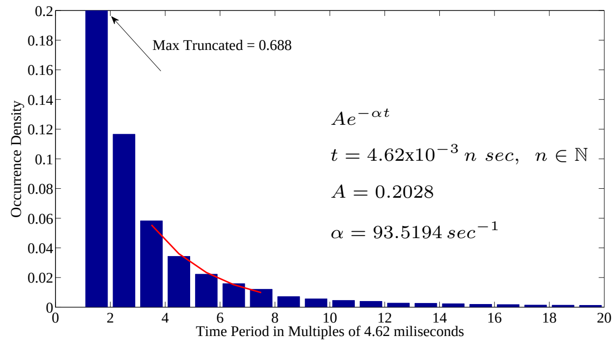

Figure 16. Time period of opportunities distribution of the measured DCS1800 band

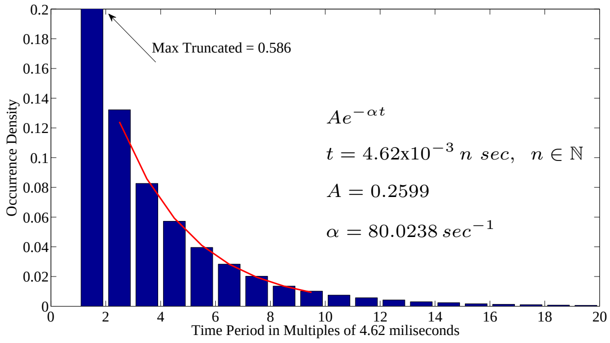

Figure 17. Time between opportunities distribution of the measured DCS1800 band

Figure 14 shows the time period of opportunities distribution for the measured GSM900 band. By doing the logarithmic of the vertical axes (turns an exponential in a straight line) it can be concluded that this distribution has an exponential behavior with the first bin ill-conditioned. An approximated straight line is obtained by the least square method. The parameters of the this straight line provide the parameters of the exponential by reverting the logarithm of the vertical axes. Figure 14 also presents the exponential approximation function (in red) and the correspondent parameters for the well conditioned bins. The total time of the opportunities is about 50 minutes in 24 hours which indicates high occupancy. About 39 minutes (of 50) is one frame opportunities. This particular band was one with lowest traffic of the entire GSM900 spectrum. Thus it can be concluded that the GSM900 spectrum is not usable for opportunistic use due to high occupancy. Figure 15 represents the correspondent time between opportunities distribution. This distribution has an exponential behavior with the first bin ill-conditioned.

Figure 16 shows the time period of opportunities distribution for the measured DCS1800 band. This distribution presents an exponential behavior with the first and second bin ill-conditioned. The total time of the opportunities is about 10 hours in 24 hours, which indicates relative low occupancy. About 2.4 hours (of 10) is one frame opportunities. It is found opportunities as long as 28 seconds (outside the horizontal axes represented in Figure 16). Figure 17 represents the correspondent time between opportunities distribution. This distribution has an exponential behavior with the first bin ill-conditioned.

V. Conclusions

In this article a measurement setup was presented and analyzed. Measurements were taken in GSM900 and DCS1800 frequency. Concerning the time period of opportunities for the measured GSM900 band from the statistic analysis, it can be concluded that the distribution has an exponential behavior with the first bin ill-conditioned. The correspondent time period between opportunities distribution (estimation) also has an exponential behavior, with first bin ill-conditioned. This GSM900 frequency has a high occupancy. The time period of opportunities distribution for the measured DCS1800 band has an exponential behavior with the first and second bin ill-conditioned. The correspondent time period between opportunities distribution has an exponential behavior, with the first bin ill-conditioned. This DCS1800 frequency has enough low occupancy to enable opportunistic use.

Acknowledgments

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