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Research Paper

Spectrum Observatory for the Improvement of Spectrum Management in Cognitive Radio Networks - Comparative Study

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Abstract: This paper describes a spectrum observatory (SO) performed outdoor in two locations in Algeria and highlights the importance of the SO in the improvement of spectrum management in cognitive radio networks. These measurements were achieved in conjunction with the ANF (Agence Nationale des Fréquences), between January and February 2020. It surveys second, third, and fourth-generation mobile networks and DVB-T frequency bands. A comparative study of two measurement campaigns (in urban & rural) that were carried out via identical setup and equipment is presented. Some major short-duration measurement campaigns are cited and summarized for the state-of-the-art. Additionally, Different statistics are imputed and 3D graphics of the spectrum occupancy are plotted to highlight the spectrum opportunities in this region. This work aims to analyze the radio environment in Algeria and identify frequency bands that could be invested for the integration of new wireless systems and Cognitive Radio opportunistic networks. The evaluation of measurement results reveals low resource occupation, lower than 30.27%, for Constantine and 8.43% for Ouargla. The final part of the study inspects the effect of specific SO features upon the management strategy parameters' selection. Via a meaningful SO, an efficient spectrum management strategy can achieve the safest users access to the idlest channels with the minimum costs and risks.

Keywords: Cognitive Radio, Measurement Campaign, Spectrum Management, Spectrum Observatory, Spectrum Occupancy Measurements, Occupancy Statistics.

1 Introduction

1.1 Overview

NEW technologies' exponential evolution and expanded usage of advanced wireless devices and applications that require high operating data rates have doubled the spectrum scarcity problem. Due to the traditional policy of static spectrum allocation, the spectrum seems congested.

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In effect, a big percentage of frequency resources around the world is, most of the time, underutilized or completely unused, this is what most studies of spectrum measurements have revealed so far.

The efforts devoted to the investment of these spectrum holes using cognitive dynamic mechanisms are still not effectively applied in most countries. However, Some associations in the US, UK, and Singapore developed new cognitive radio (CR) policies and devices to invest in TV white spaces, like "Whizepace Pte Ltd – Singapore – 5 years ago", or to transfer Wi-Fi users to the free 5-GHz Wi-Fi band like in [1]. Therefore, the challenge has been rose to propose new mechanisms for spectrum management via extended surveys and studies of the radio environment variation patterns. The new techniques and systems relying on CR that are being developed lately are standing essentially on the comprehensive analysis of spectrum behavior and the intelligent dealing with channel occupancy variability in time, frequency, and space to achieve an efficient spectrum allocation for unlicensed opportunistic spectrum users. The importance of a spectrum observatory is that it provides an interesting detection and characterization of the spectral holes in time and space [2] that is useful in the management of radio frequency resources. Technologies like M2M, IoT, smart grid networks, and urban connectivity based on Super Wi-Fi or TV white space spectrum communications require a deep spectrum status study for better reuse of spectrum opportunities.

1.2 The Importance of Spectrum Observatory in a Spectrum Management System

In the close future, spectrum resources will be used opportunistically via CR technology. This technology has been invested illegally during the last decade but actually, it will not stay without normalization. In our vision, as peer to other wireless technologies like mobile communication services (2G, 3G, 4G, …), the CR technology will be adopted by countries' regulatory bodies, and by their turn, they will attribute and allocate it to spectrum operators. In this way, the spectrum will be allocated in a licensed opportunistic manner. In our model, the management and handoff of radio resources for all operators will be supervised via one spectrum observatory and management system for each geographic area, and via dynamic sharing protocols, Secondary Users (SUs) will share the available channels. Finally, the system calculates the cost and the resource usage percentage for every operator. Figure 1 illustrates the role of the spectrum observatory and management system in a Cognitive Radio Network (CRN).

A good management strategy is that ensures an accurate mobility mechanism, which guarantees safe transitions of SUs between available frequency bands and avoids interferences with Primary Users (PUs). A robust spectrum mobility algorithm can be achievable via an efficient spectrum allocation and sharing scheme. These latter functions are responsible for the dynamic attribution of the radio spectrum and the intelligent exploitation and sharing of frequency opportunities. However, the allocation of spectrum resources without handoff delays requires prior knowledge of the channels' status, which is provided by the spectrum prediction process.

A prediction algorithm relies essentially on the occupancy information acquired from a meaningful spectrum observatory that makes the right decision rules for reliable sensing results. Figure 2 shows the spectrum management functions gradation.

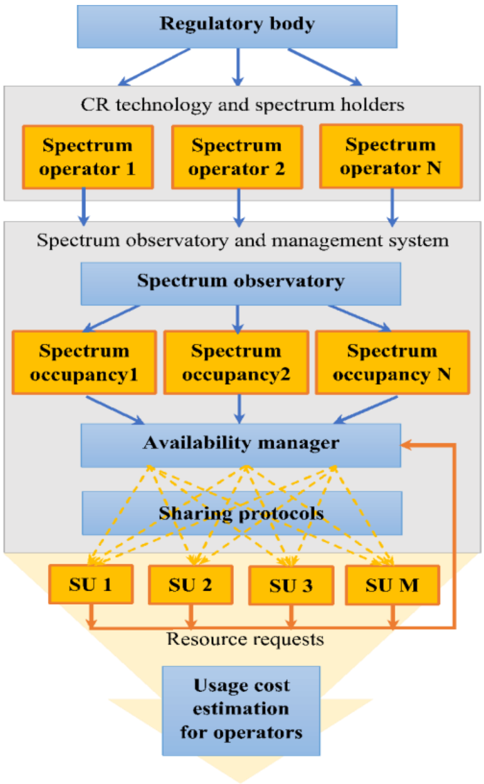


Fig. 1 The role of the spectrum observatory and management system in a CRN.

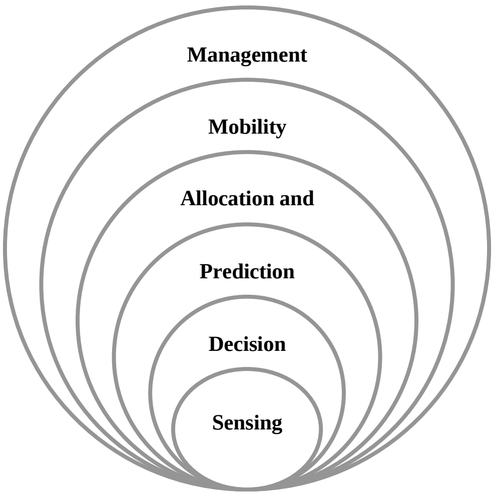


Fig. 2 Spectrum management functions.

In a CR spectrum management system, a spectrum observatory has the responsibility of continuous spectrum monitoring, data gathering (database collection of spectrum characteristics and geo-localization information), estimation and evaluation of frequency bands occupancy status, and more. Its objective is to classify frequency channels according to their usage categories (idle, busy, etc), and to extract relevant spectrum information and features for an accurate users' detection, therefore, the modeling of the PUs activity. All these collected data will be then exploited in the training of prediction [3], allocation, and mobility algorithms for an efficient resource handoff for SUs and to reduce transaction costs. Figure 3 presents the proposed CR spectrum management scheme and highlights the position and role of a spectrum observatory in this system.

1.3 Related Works

Until understanding how much spectrum is occupied? And how well is used? Are there opportunities to integrate new users, new services, and new technologies? The occupancy and availability of different spectrum bands have been surveyed in many places around the world like in Chicago [4], in Singapore [5], in Spain [6], in Germany [7], in Finland [8], [9], and few works in African and Arabian region have been done except those performed in South Africa [10], in Nigeria like [11], and in Morocco [12], etc and as well as in Algeria via the present work.

Under the title of "spectrum measurement & analysis or spectrum survey for the implementation of a dynamic spectrum access system", these works have opened the perspectives for the new concept of cognitive radio and the development of its diverse applications. Table 1 illustrates the literature review of some short-duration measurement campaigns.

1.4 Contribution

This work provides detailed spectrum scan statistics for every tiny channel for different spectrum services. This measurement campaign aims to, first, highlight the importance of a spectrum observatory in a spectrum management system. Second, to study the spectrum occupancy behavior in specific geographic regions (urban and rural) by extracting the PUs activity in these areas, then to compare the results. Especially, to assess the potential of using CR or any other system based on the principle of dynamic spectrum allocation. Moreover, to build a real database that contains an updated spectrum occupancy scenario. This database is used next in solving diverse CR issues like spectrum sensing, prediction, allocation, sharing, and management. This contribution resides essentially in providing a recent and detailed spectrum occupancy survey of the actual mobile networks and DVB-T frequency bands and compares the results of the same measurements carried out in two different areas in Algeria, Constantine and Ouargla.

1.5 Organization of the Document

The rest of this paper is organized as follows: Section 2 defines the measurement system, its technical characteristics, and key features, used in this measurement campaign. Section 3 describes the considered data collection and analysis methodology in addition to the main parameters and settings of the measurement procedure. Spectrum occupancy statistical and graphical results are provided in Section 4, side-by-side with an investigation of the effect of spectrum observatory upon the management strategy selection. Finally, conclusions are summarized in Section 5.

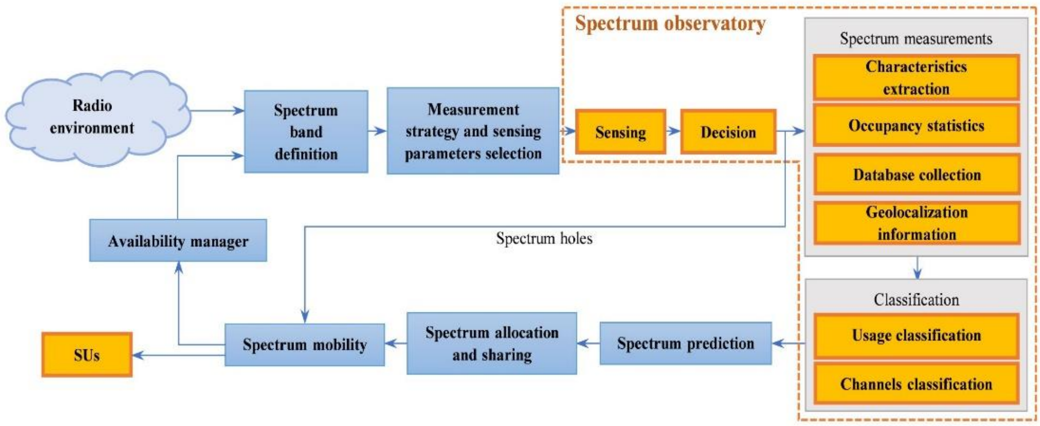


Fig. 3 The proposed CR management system scheme.

Table 1 Summary of some related short-term measurement campaigns.

Location	Frequency band	Period	Threshold	Sweep time	Materials and Software	Important results
Chicago, IL [4]	30 to 3000 MHz	2 days	Varies from one band to another Fixed in the same band	/	SSC-designed high linearity preselector, omnidirectional discone antenna, small log-periodic array (LPA) for frequencies <1000 MHz	The overall usage for Chicago city is 17.4%
Singapore [5]	80 MHz to 5.85 GHz	12 weekdays	6 dB above the noise floor	13.8 min	BiConiLog directional antenna (model 3149), E4407B Agilent's spectrum analyzer, Labview8.2	Average occupancy for the whole range of frequency = 4.54%
China [13]	20MHz to 3GHz	1 week	(dynamic) 3 dB higher than the minimum signal value of the channel	75 sec	R&S EM550 super-heterodyne VHF/UHF Digital Wideband Receiver (20 MHz - 3.6 GHz)	High temporal / spectral / spatial correlation for the service congestion rate (SCR) series > 0.7, and high spectral correlation between Channel state information (CSI) series within the same service.
France (Paris) [14]	400 MHz to 6 GHz	12 weekdays	7 dB above the average noise floor	401 sec	Broadband logarithmic periodic antenna, spectrum analyzer, MATLAB	Spectrum usage in this band and in a specific region is less than 5.3%. Comparison with the Czech Republic.
Beijing [15]	450 to 2700 MHz	2 weeks	5 dB above the noise floor	0.42 sec	Omnidirectional BOGER DA-5000 broadband antenna (70MHz-3GHz), Agilent N9030A Spectrum Analyzer	The average spectral occupancy in Beijing is about 13.5%
HULL-UK [16]	180 to 2700 MHz	12 days	5 dB above the average received signal power	Auto (selected by the spectrum analyzer)	Bilog Antenna CBL 6143 (30-3000 MHz), Agilent E4407B spectrum analyzer, MATLAB	The average spectrum occupancy of the whole frequency range was 11.02 %
Finland [17]	2.3 – 2.4 MHz	2 weeks	Fixed to - 93 dBm	3 sec	Broadband omnidirectional and multi-polarized antenna (85-6000 MHz), CRFS RFeye receiving spectrum analyzer, data storage, and data transfer equipment	More than 90 % of the spectrum was shown to be idle in one specific measurement location in Turku, Finland. The 2.3 GHz band has potential for the LSA concept in Finland.
Nigeria [11]	2.4 to 2.7 GHz	24 hours	10 dB above the noise floor	34.10 ms (Automatically selected by the spectrum analyzer)	Data storage device, data manipulation equipment (laptop), Agilent N9342C Handheld Spectrum Analyzer (HSA)	The investigated band is immensely underutilized with upper and lower occupancy values of 22.56% and 0% in urban and rural environments, respectively.
UK [18]	2.4GHz WLAN	20 min	10 dB above the noise floor	204.8 µsec	Wideband omnidirectional discone antenna (1st setup), three commercial log-periodic vertically-polarized antennas (directional setup), sensing engine, workstation.	Omnidirectional and directional measurement setups: Gamma and lognormal distributions can model the idle state of a 2.4 GHz WLAN channel along with the generalized Pareto distribution.
Samsun - Turkey [19]	700 to 2700 MHz	1 week	10 dB above the noise floor	/	RF Explorer 6G Combo spectrum analyzer, connected dongle to the laptop, MATLAB	The average occupancy of all services is 16.06%. 50% of the locations occupancies is below 20% for the LTE, and below 33% for GSM900 and UMTS2100.

2 Measurement System

Compared to the data collected otherwise, the actual data is collected using a professional signal monitoring system. Where the collection of similar data requires hard work, to provide the required hardware "large span, wide range, multi-directional, and high sensitivity antenna" to cover all area directions, and a "spectrum analyzer"; especially to interface your hardware with the software using specific drivers. Then to build a "LabVIEW" or "MATLAB" corresponding diagram/model which catches the analyzed signal and processes it until getting the final useful frequency samples. This process may take a lot of time and complexity, appreciably, when dialing with long rang frequency span measurements and short-duration storage intervals. In the present measurements, all this process was summarized in one system "TCI 5093 Spectrum Processor" which can analyze and process multiple signals from different azimuths, with various spans and Resolution Bandwidths (RBWs) for diverse durations and sampling times. All these functions are done in parallel due to its important processing capabilities and its associated "Scorpio" software in addition to the "647D: V/U/SHF DF" Dual polarization multidirectional monitor and DF antenna array. The measurement system is shown in Fig. 4.

(a) 647D Dual-Polarized (VHF/UHF/SHF) DF and multidirectional monitor antenna array.

(b) TCI 5093 Spectrum Processor and Receiver.

(c) PC with “Scorpio” monitoring software.

Fig. 4 Spectrum Measurement equipment in both areas.

2.1 Antenna Technical Characteristics

- Antenna Model: 647D Dual-Polarized (VHF/UHF/SHF) DF and multidirectional monitor antenna array. It consists of three major components; the antenna radome, the dual block converter module, and the POE (Power Over Ethernet) control interface module. Inside the radome are two DF antenna arrays (one is for the VHF/UHF band and the other is for the SHF band), a reference antenna, and a C-Band DF antenna switch unit. The 647 Dual-Polarized antenna generates three RF outputs; a “Monitor”, “Reference” and “Sample” RF outputs. These two last outputs feed directly the dual-channel block converter and then feed the 2612 VHF/UHF receivers [20];
- Frequency span: 20 - 8000 MHz;
- Coverage range: 30 km;
- Sensitivity: System sensitivity is the field strength (dBìV/m) required to provide specified DF accuracy including antenna noise figure, coax cable losses, and receiver noise figure; referenced to 1 Hz bandwidth and with 1-second DF averaging [19]. It is illustrated in Fig. 5.

3 Methodology for Data Collection and Analyses

3.1 Measurement Locations

Measurement Areas have been selected in this work as two different nature locations (urban and rural) to study the probability of the integration of a Cognitive Radio Network (CRN) in different environments in Algeria, by extracting and classifying spectrum occupancy patterns and detecting possible spectrum opportunities. A comparison of the spectrum occupancy between these two locations is presented in section 4. The first location was in the outdoor, upper-roof of the department of political sciences at the campus of Salah Boubenider, University of Constantine 3 – Constantine, whereas the second location was outdoor in the rural area – Bour Al-Aîcha – in Ouargla. The coordinates and measurement settings are noted in the Table 2, and google maps locations are presented in Fig. 6.

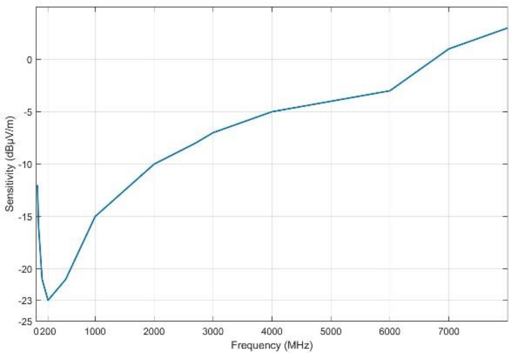
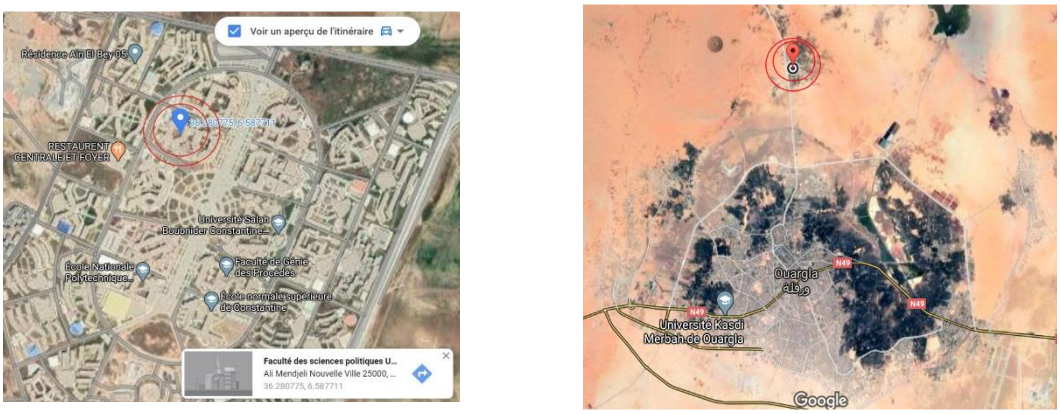


Fig. 5 Antenna sensitivity (dBμV/m) Vs Frequency in (MHz) [20].

3.2 Measurement procedure and strategy

In wide-band spectrum surveys, it is so important to compromise between the measured band and the time duration.



(a) (b)

Fig. 6 Spectrum survey locations, (a) Constantine, (b) Ouargla.

Table 2 Spectrum data collection settings.

Measurement parameters	Parameters values
Collection instrument	TCI 5093 Spectrum Processor
Collection locations	**Two areas (Algeria):** ▪ Urban in the university of Salah Boubnider – Constantine ▪ Rural in Bour Al-Aîcha – Ouargla
Location coordinates	▪ Constantine : N 36 16'52,3" E 6 35' 15,4" ▪ Ouargla: N 32 0' 46,1" E 5 20' 11,9"
Sampling time (scan) interval	5 min

Where any measurement hardware has some limits in terms of the registration capacity, i.e., the number of received/memorized samples. Short sampling time and short sampling frequency scan require a brief analyzing band because it produces a high number of received samples, and thus a big storage space. Therefore, the measured data has been gathered continuously by “five minutes” sampling time, for 24 hours, during 7 and 15 days across multiple frequency channels in two different areas. Sampling frequency for each band was carried out according to their regulatory bandwidth restrictions. It was set to be taken in the middle of channels to ensure the right detection of the signal power.

The used equipment surveys the required frequency bands by detecting the field strength of active users in this band during the selected period. This was achieved via the antenna array that detects the field strength (dBµV/m) of all selected frequency bands according to the measurement tasks coming from the Scorpio spectrum monitoring software interface that allows the definition of all measurement parameters. The TCI 5093 Spectrum Processor and Receiver acquires the field strength samples for every slot time and calculates the usage occupancy in time, which is known by the term of (duty cycle). Real-time spectrum occupancy or duty cycle (DC) (%) can be expressed as follows:

$$DC\ (\%) = \frac{occupied\ period}{Total\ observation\ period} \times 100 \quad (1)$$

Where the occupied period is how much time this channel was occupied during the total observation period. This last is the sampling slot time, and it is equal to (5 minutes).

Channel field strength E in (dBµV/m) is related to signal power by the following equation:

$$P_{rx} = E - 20 * log\ (f)\ - 77.21 + G_i - L_f \quad (2)$$

Where P_{rx} is the received signal power at the receiver antenna in (dBm), and E is the Electrical field strength propagated in the space given by:

$$E^2 = P_r * 120\pi \quad (3)$$

Where P_r is the radiated signal power. f is the frequency in (MHz), $G_i(dBi)$ is the isotropic antenna gain, and L_f is the path loss.

In our measurements, a dynamic threshold was used to detect the occupancy states of each frequency channel during the time. The adopted decision threshold for each frequency sampling point is set to 10dB above the noise level, this mode of dynamic thresholding is known in practice (by the ITU) as the “Noise Riding threshold method”.

Table 3 List of scanned bands with all details.

	Band	Band number	Start-stop Frequencies (MHz)	Sampling frequency (kHz)	Number of channels per band	Campaign period by days
	GSM900 (Up-Link)	1	890 - 915	200	125	15
	GSM900 (Dn-Link)	1	935 - 960	200	125	
Constantine	GSM1800 (Up-Link)	1 2 3	1730.1 – 1732.5 1747.6 – 1752.8 1763 – 1770.8	200	13 27 30	7
	GSM1800 (Dn-Link)	1 2 3	1825.1 – 1827.5 1842.6 – 1847.8 1858 – 1865.8	200	13 27 30	7
	4G (Up-Link)	1 2 3 4	1710.01 – 1729.99 1732.61 – 1747.49 1752.9125 – 1762.8875 1770.9125 – 1780.8875	15	1332 993 666 666	7
	3G (Dn-Link)	1	2110 – 2170	200	300	7
	DVB-T	1	470 – 862	/	/	/
Ouargla	GSM1800 (Up-Link)	1 2 3	1730.1 – 1732.5 1747.6 – 1752.8 1763 – 1768.8	200	13 27 30	7
	GSM1800 (Dn-Link)	1 2 3	1825.1 – 1827.5 1842.6 – 1847.8 1858 – 1863.8	200	13 27 30	7
	4G (Up-Link)	1 2 3 4	1710.01– 1729.99 1732.61 – 1747.49 1752.9125 – 1762.8875 1768.895 – 1783.295	15	1332 993 666 961	7
	3G (Dn-Link)	1	2110 – 2170	200	300	7
	DVB-T	1	470 – 862	/	/	/

This value was used to free the received signal from any possible adjacent transmitters' noisy signals.

The measurement bands and details are clarified in the Table 3.

The presented (Start-stop Frequencies) of the GSM1800 and the 4G bands are the effective frequency limits of these bands for the indicated measurements period between January and February 2020. Recently, these bands are modified by the extension of the 4G operating bandwidth from 10 MHz to 15 MHz by 2021. In addition, mobile operators, in 2021, extended 4G service to the 3G band, where every operator has been attributed one more 5MHz bandwidth additionally to the three previously attributed for each of them to 3G. In this way, 10 to 15MHz would be allocated to the LTE, for data transmission, and the rest of the bandwidth to the 3G, for voice transmission.

For GSM1800, the band numbers 1, 2, and 3 are respectively the frequency bands of the operators, Djezzy/Optimum Télécom Algérie (OTA), Mobilis/ Algérie Télécom mobile (ATM), Ooredoo/Wataniya Télécom Algérie (WTA). Whereas, the numbers 1, 2, 3, and 4 for 4G band are Algérie Telecom (AT), Djezzy (OTA), Mobilis (ATM), Ooredoo (WTA), correspondingly.

Besides, we did not analyze the DVB-T band continuously since the resource utilization in this band is static. Where in each city in Algeria, one to three channels only are used for TV TNT (Télévision Numérique Terrestre). In the first site in Constantine, two DVB-T channels of 8MHz are active all the time in the frequency bands of (510 – 518MHz) and (526–534). Otherwise, the rural area in Ouargla covers only one channel between (486 and 494MHz). This is since the allocation of TV channels depends on the geographical location.

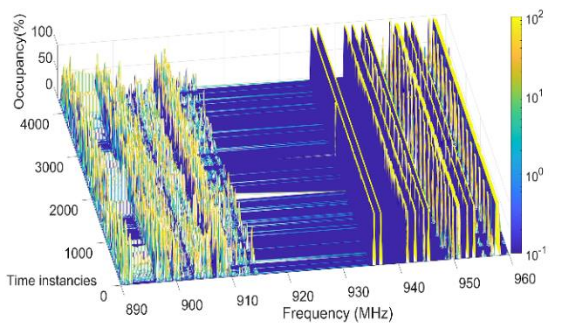
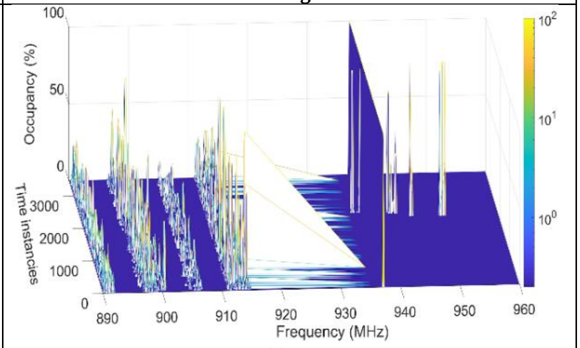
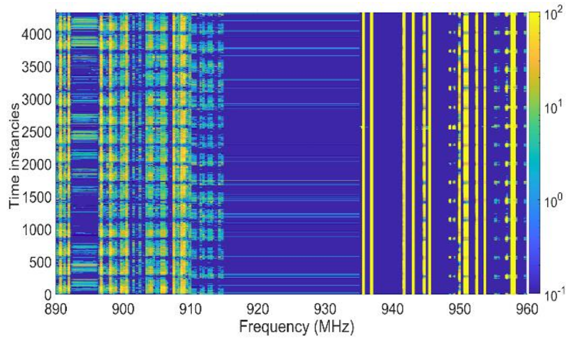
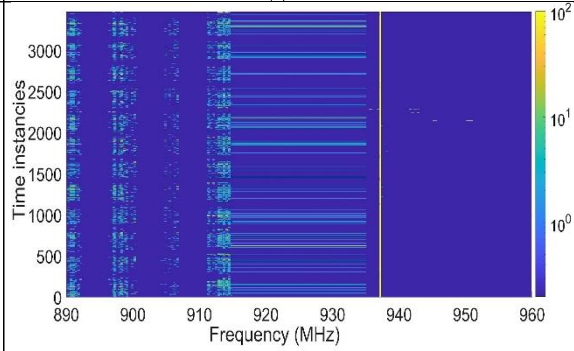
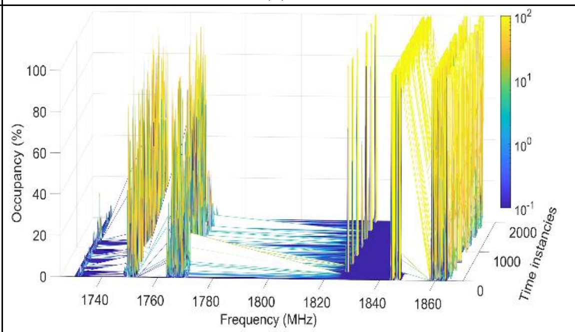
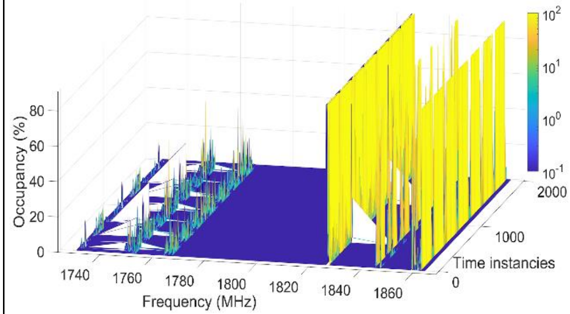
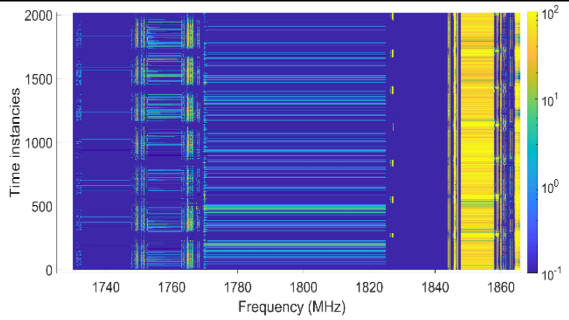
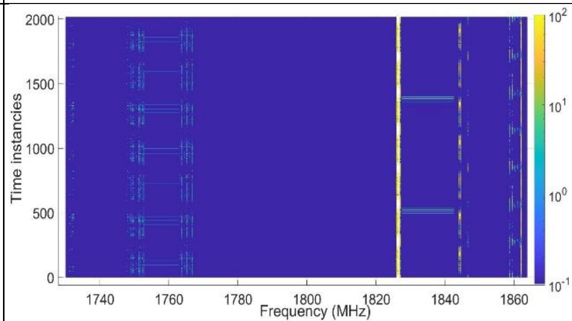
In another hand, for the third generation (3G) too, we have, only, observed the down-link span in (2110–2170MHz). This band is almost full; every operator has been attributed three consecutive channels of (5MHz), and a guard interval of 10.55MHz appears the only spectrum opportunity in this frequency range in addition to 5.15MHz at the end of the band. Up-link signals in the 3rd generation are considered as undetectable looking to the spread spectrum distribution technique that hides transmitted signals under the noise floor. Knowing that only FDD (Frequency-division duplexing) is functioning in Algeria.

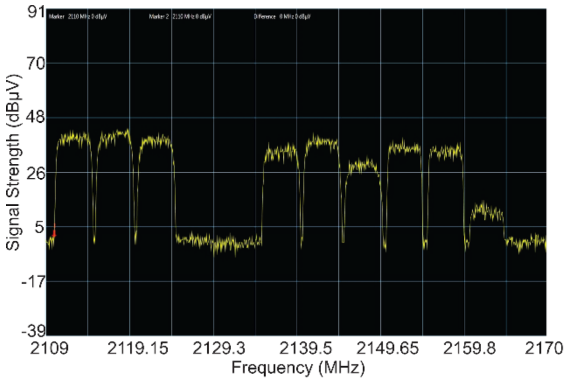
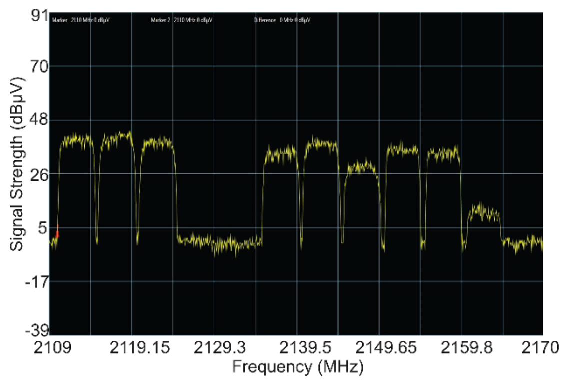
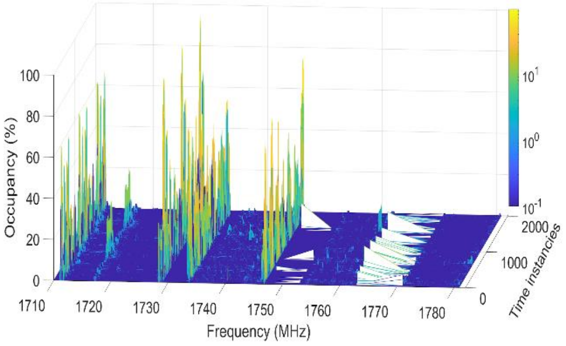
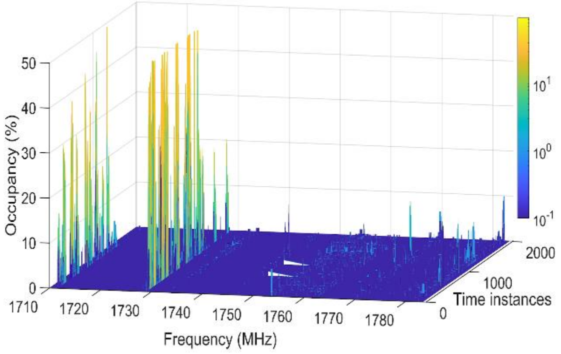
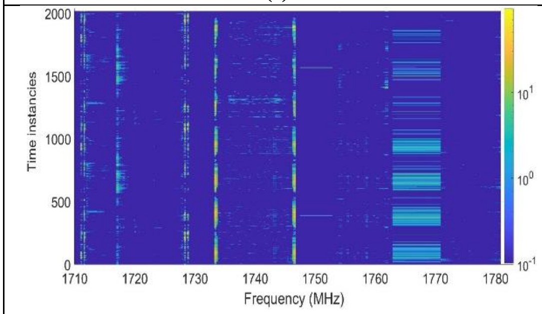
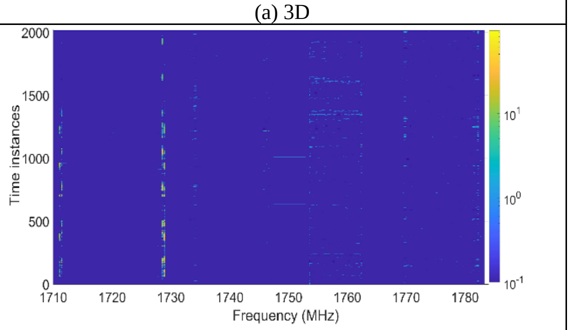
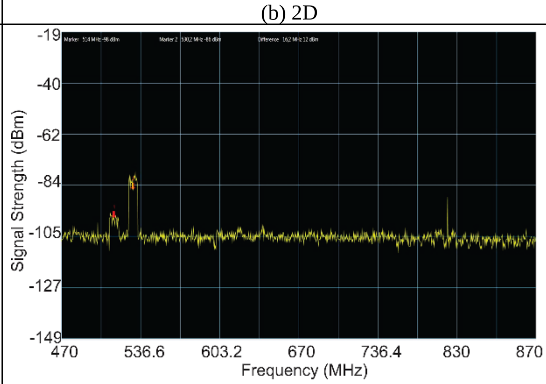
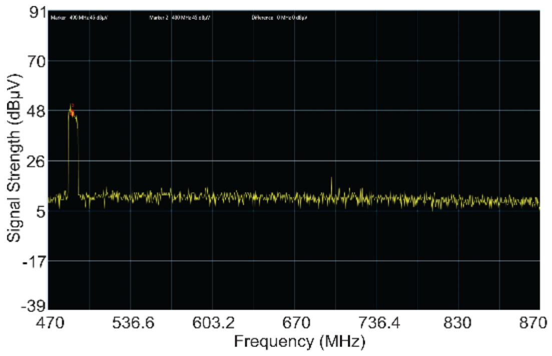
4 Spectrum Occupancy Results, Statistics, and Discussions

4.1 Graphical Results

Using MATLAB toolbox, all collected data were plotted in 3D and 2D graphs to visualize the general evolution of Primary Users (PUs) spectrum occupancy. This visualization can give us a good overview about PUs activity and the potential underused frequency sub-bands. Thereby, the evaluation of available radio resources and the estimation of the possible investigation and management strategies of this precious resource. Table 4 shows the spectrum Occupancy graphical results of all analyzed bands for the urban and rural areas.

Table 4 Spectrum occupancy graphical results of surveyed bands, (a) 3D and (b) 2D graphs.

	Constantine	Ouargla
GSM 900	 (a) 3D	 (a) 3D
	 (b) 2D	 (b) 2D
GSM 1800	 (a) 3D	 (a) 3D
	 (b) 2D	 (b) 2D

3G (Down-Link)	 (b) 2D	 (b) 2D
4G (Up-Link)	 (a) 3D	 (a) 3D
	 (b) 2D	 (b) 2D
DVB-T	 (b) 2D	 (b) 2D

By observing the spectrum occupancy behavior in the Table 4, it is remarkable that the occupancy variation during a day is quite similar throughout 15 days of the measurement campaign.

4.2 Statistical results

The occupancy percentages of the collected data were averaged band-by-band, operator-by-operator for both regions. Besides, the average occupancy values for every operator and the total occupancy per band have been calculated in terms of the total number of samples of the considered service band. Equation (4) was used to impute the statistical results:

$$\textit{Average occupancy per band} = \frac{N_{os}}{N} \quad (4)$$

N_{os} is the number of occupied samples, and N is the total number of samples per band.

The statistics are collected in the Table. 5, and the occupancy values are presented using bar charts in Figs. 7, 8, and 9.

It can be observed that GSM bands are more occupied than the fourth-generation bands because for GSM the two links, Up and Downlink occupancies, are considered, which raised the occupancy in that bands. Whereas WTA mobile operator possesses the highest occupancy percentage in Constantine for GSM bands by 15.99% in GSM1800, and OTA in the second place by 11.45% for GSM900. However, OTA marks the highest occupancy value for GSM in Ouargla with 4.05%. In another hand, the third-generation band presents the maximum levels of occupancy with an average occupancy of 73.84% from the total 3G Downlink bandwidth in both areas.

Table 5 Average spectrum occupancies of analyzed bands in terms of mobile operators and measurement areas.

Areas	**Constantine Occupancies (%)**					**Ouargla Occupancies (%)**				
Bands Operators	**GSM900**	**GSM1800**	**3G**	**4G**	**DVB-T**	**GSM900**	**GSM1800**	**3G**	**4G**	**DVB-T**
Algérie Télécom	/	/	/	1.1116	/	/	/	/	0.2831	/
OTA	11.4537	0.5525	24.61	1.4105	/	0.2771	4.0462	24.61	0.0218	/
ATM	9.0137	8.4629	24.61	0.1273	/	1.0624	2.1510	24.61	0.0883	/
WTA	9.7938	15.9927	24.61	0.0522	/	0.8116	2.2311	24.61	0.0670	/
Total occupancy per band (%)	30.2612	25.0512	73.84	2.7016	4.0816	2.1511	8.4283	73.84	0.4602	2.0408

Fig. 7 Spectral Occupancy for all bands in terms of mobile operators in Constantine.

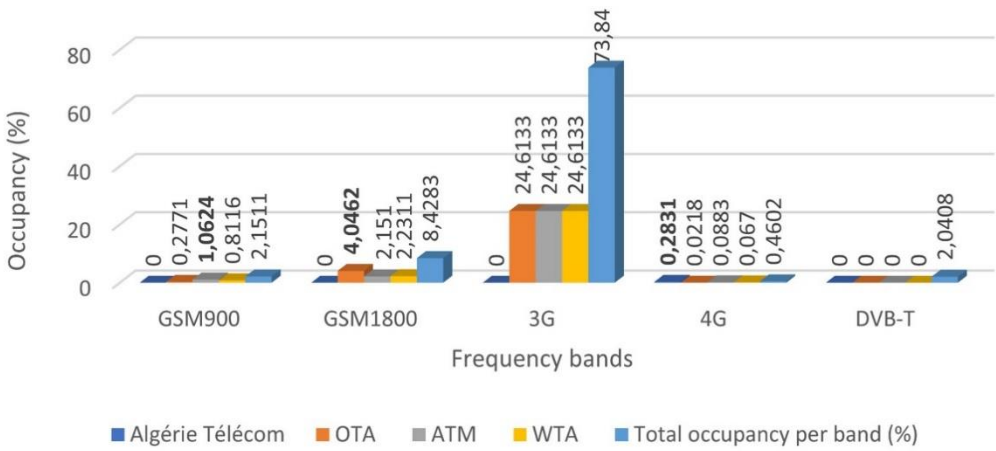


Fig. 8 Spectral Occupancy for all bands in terms of mobile operators in Ouargla.

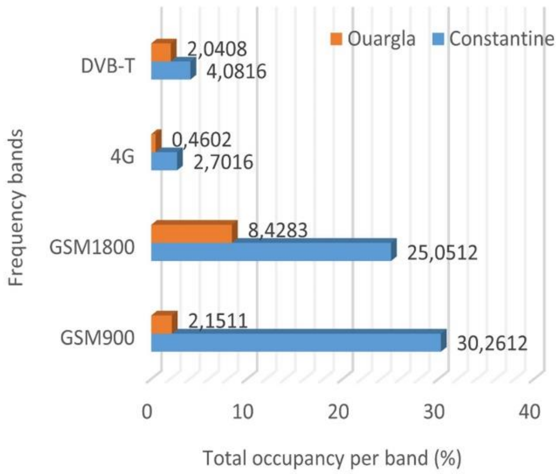


Fig. 9 Overall spectral occupancy comparison between Constantine and Ouargla.

To investigate the amount of fully idle channels versus the other occupied channels in all the measured bands, and to distinguish the occupancy levels of radio resources the following classification was performed. As an example, the GSM900 band dataset has been used in this first investigation. The number of channels with zero utilization, out of the total number of channels in this specific band (250 channels), was summed for every time slot to get the "Free Channels" number for 15 weekdays, instant by instant. Similarly, the number of "Under-used" and "Highly-used" channels was determined. Whereas occupancy samples belong to [0, 50%] were classified as "Under-used" channels. However, "Highly-used" channels were considered as channels of more than 50% occupancy values, view Fig. 10. In this way too, the total number of samples by each class of channels was summed and divided by the total number of samples in a specific band. The results are presented in Figs. 11 and 12.

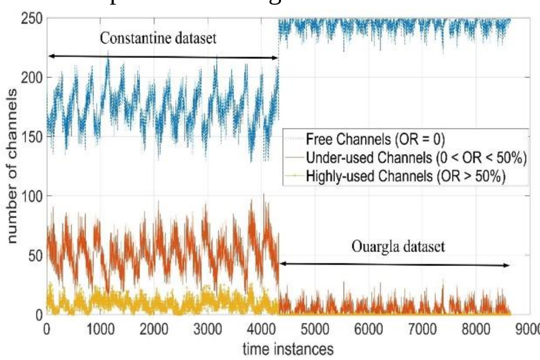


Fig. 10 Channels classification of Constantine and Ouargla for the GSM900 band.

As it can be observed in Fig. 10, it is remarkable that the number of free channels is the highest compared to under-used and highly-used channels, during the whole measurement period for both areas. It can be observed that in the rural area, the channel opportunities are away bigger than the used channels number. Moreover, the under-used and highly-used number of channels are quite similar and curves are distinguishable between free and used classes in this area.

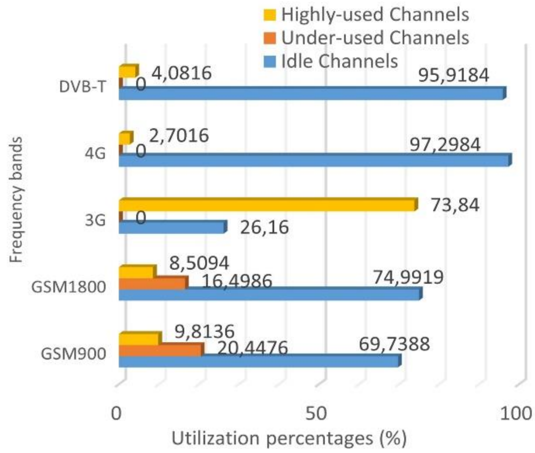


Fig. 11 Overall utilization percentages of classified channels for Constantine.

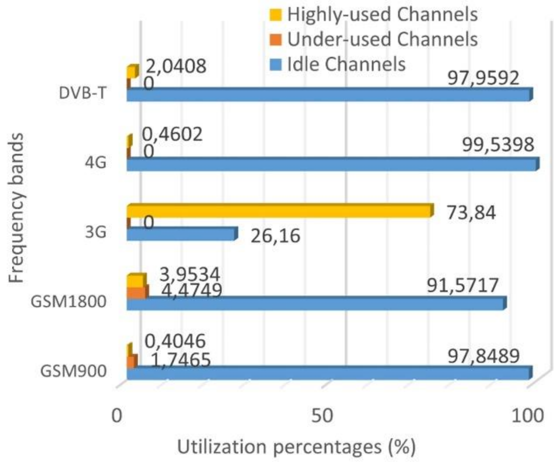


Fig. 12 Overall utilization percentages of classified channels for Ouargla.

The overall occupancy in a specific area depends on a lot of standards; it is difficult to compare it inclusively. It depends on the area (urban or rural), the year of the measurements and the wireless technologies spreading in that area and that time, the spectrum range of the study and the occupancy rate of each network including in it, and the period of time (days, weeks) of the spectrum survey, etc. Whereas, the above-mentioned relevant works are only short duration measurements that survey approximately the same frequency range and measurement duration as our study.

From Fig. 13, it can be extracted that the overall occupancy (%) in the urban area of our study is too close to these of relevant works that were executed during the years from 2013 to 2021 [19], [15], [16], in addition to that done in Chicago [4]. This last can be explained by the high population density/users' number in that area in 2006. However, compared to [11] the overall-urban occupancy in Nigeria is higher than in Algeria.

From another hand, the overall-rural occupancy in Algeria is closer to the overall occupancy in [5] and [14] that have been performed in 2008 and 2009, respectively.

4.3 Spectrum Observatory Impact upon Management Strategy

To inspect the effect of specific spectrum observatory features upon some management strategy parameters, the occupancy in percent and the field strength of the first five minutes, thirty seconds, and three seconds of three GSM900 channels were tested and selected management choices were deduced in Table 6.

Fig. 14 shows the spectrum occupancy of a sample channel for different sampling times (5min, 30s, and 3s).

The selection of the management strategy in practice depends on different parameters, one of those parameters is the probability of interference between secondary and primary users. This parameter is directly related to the sampling time. Whereas, big sensing steps would miss the detailed detection of PUs in time, which increases the probability of collision with PUs. However, reducing sampling time by rising the sensing frequency or the number of samples per time element inflates the processing requirements. Especially, during frequency resources' handoff, the Software Defined Radio (SDR) device performs multiple numbers of channels' switching for SUs because of short transitions in time. This can also engender spectrum access delays and interferences caused by the switching delays.

Otherwise, reducing sensing time is beneficial in terms of the decreased probability of interference and the increased availability rates, and thus high spectrum opportunities detection. Short sensing time enables SUs to use even underutilized channels in time and frequency domains but it consumes higher energy and memorization capacity for high sensing frequency.

The example in Table 6 proves the impact of specific spectrum observatory features upon some management strategy parameters.

Through the above results the sampling time, channel occupancy, and field strength effect on the management strategy was investigated. Thereby, the CR spectrum management system in this case selects the least-occupied channel with lower field strength and probability of interference to be allocated for SUs whatever the selected sensing time.

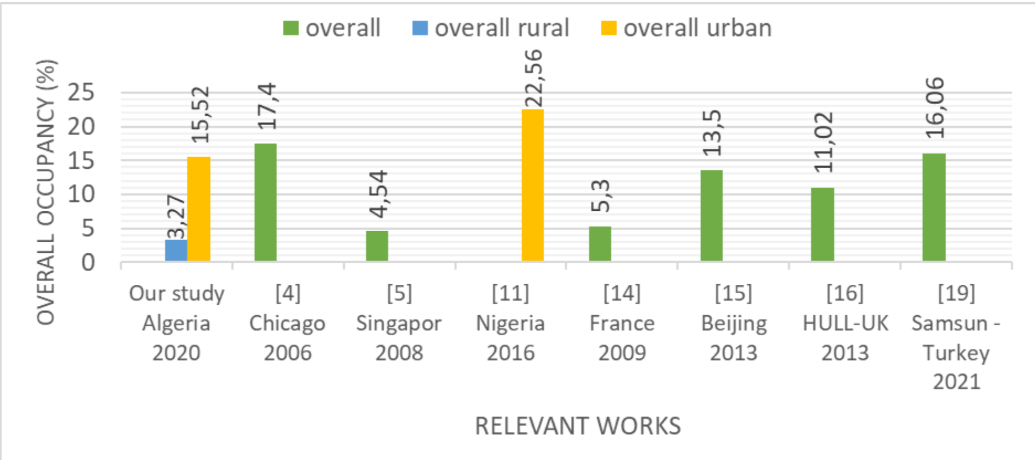


Fig. 13 Overall occupancy comparison with relevant works.

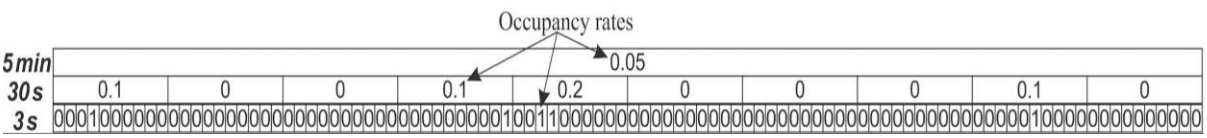


Fig. 14 Spectrum occupancy of a sample channel for different sampling times for five minutes duration.

Table 6 Spectrum observatory impact upon the management strategy.

Spectrum Observatory Features				Management Strategy Parameters				
Sampling Time	Channels	Channel Occupancy (%)	Field Strength (dBμV/m)	Channel Selection	Probability of interference	Availability rate	Number of channels switching per 5min	Sensing frequency
5 min	Channel 1	5	53		0.05	0	1	$\frac{1}{100} = 0.01$
	Channel 2	7.49	58	X	0.0749	0	1	
	Channel 3	5	57	X	0.051	0	1	
30 s	Channel 1	10	49	X	0.001	0.6	4	$\frac{1}{10} = 0.1$
	Channel 2	0	0		0	0.5	5	
	Channel 3	6.6	46	X	0.0066	0.5	5	
3 s	Channel 1	0	0		0	0.95	5	1
	Channel 2	0	0		0	0.86	14	
	Channel 3	33	46	X	0.0033	0.95	11	

4.4 Summary

Throughout the statistical results, the DVB-T spectrum band presents a substantial opportunity for spectrum reuse, especially concerning the typical propagation characteristics of electromagnetic waves in this particular band. As well, other mobile operating frequency resources are partially available during the time of the day, which offers access for dynamic opportunistic secondary users. Moreover, the operator-by-operator spectrum analysis used in this study can assist in the normalization and regularization of dynamic spectrum access policies between operators for unlicensed users in the future. Therefore, the implementation of a CRN is beneficial in both specific areas in Algeria, since the electromagnetic spectrum is not fully used even if it is already fully allocated.

A CR spectrum management strategy should consider many parameters before performing the necessary spectrum measurements. Whereas, a good strategy is which achieves the best results with the minimum costs and risks.

5 Conclusion

The spectrum occupancy observatory has uncovered the real status of spectrum usage around the world and thus it opened the horizons to new strategies of spectrum management and the new applications of cognitive radio. According to the results of this study, Algeria has a big opportunity to implement any new cognitive radio network that is based on opportunistic and dynamic access technics. Looking at the high number of idle and under-used channels in time presented in a large part of under-used frequency bands, it can be deduced that the traditional method of fixed radio resources allocation would induce a serious spectrum scarcity problem. Therefore, a spectrum observatory management system is necessary to reduce scarcity problem using dynamic spectrum allocation. The overall occupancy percentage of mobile communication and DVB-T bands for both locations of Algeria does not exceed 30.26%, which means that the reuse of these resources in new technologies like IoT, 5G, etc. is highly recommended especially in rural areas that have low spectrum congestion compared to urban areas.

To determine the spectrum utilization in a specific area and to compare it with occupancy results of another area, several important criteria must be considered including; the nature of this area and its specifications, spectrum band to be measured, kind of technologies included in this band, the duration and the year of the survey, etc.

In our vision, a good CR spectrum management strategy is a strategy that combines sensing, prediction, and allocation functions to ensure minimum interferences, and processing requirements.

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The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing to publication, with respect to intellectual property.

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S. Tidjani: Research & Investigation, Original Draft Preparation, Revise & Editing. **Z. Hammoudi:** Supervision, Verification, Methodology.

Declaration of Competing Interest

The authors hereby confirm that the submitted manuscript is an original work and has not been published so far, is not under consideration for publication by any other journal and will not be submitted to any other journal until the decision will be made by this journal. All authors have approved the manuscript and agree with its submission to "Iranian Journal of Electrical and Electronic Engineering".

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