

# Evaluation of TVWS Availability: A Step Towards Frequency Spectrum Utilization

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## ABSTRACT

In this era, there are several multimedia applications have been developed. These multimedia applications occupy more bandwidth, thus resulting in the scarcity of frequency spectrum necessary to cater to the bandwidth requirements of these applications. The scarcity may also stem from the licensed spectrum being under-utilized. The unused licensed frequency spectrum in the TV band is known as TV white space. In the coming years, which are expected to feature improved multimedia applications, the need for optimal frequency spectrum utilization of the unused licensed spectrum becomes necessary. This study evaluates the availability of Television White Space (TVWS) in Ondo State radio vision-television station in Akure, south western Nigeria. Outdoor spectrum measurement was carried out in the frequency bands of the licensed networks ranging from 470 MHz – 960MHz. Measurement and computational approach using tiny spectrum Analyzer and protection viewpoint computational method was used for easy detection and analysis of the unused spectrum as well as calculating the radius of protection of the primary user. The study permits the assessment of Radio Frequency (RF) Spectrum in the UHF band in Akure and its environments, as well as providing measures for harnessing the unused RF resources. The results obtained show that 71.05% of the 38 channels were unused. The rate of spectrum occupancy was discovered to be very low, thus giving room for unused spectrum spaces in the UHF frequency band which can be used to provide security surveillance.

Keywords: Broadband Connectivity, GSM Network, Licensed Spectrum, Surveillance, UHF, Unlicensed Spectrum, TVWS.



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## 1 Introduction

With the current advent of high bandwidth multimedia services and applications as well as the growing demand for large information network access for mobile wireless devices, it is obvious that there will be a continuous increase in demand for more bandwidth by both wireless services providers and users. Although it is a general belief that the frequency spectrum is scarce and under-utilized. Nevertheless, Television White Space (TVWS) provides a huge and wider opportunity as a companion to licensed spectrum to ease this scarcity. With spectrum thump, communication is expected to increasingly look for the alternate way for more efficient use of spectrum. Given this, research studies have focused on measurements and the potential of TVWS for broadband internet access [1]-[8]. A host of other applications of TVWS, such as healthcare and agriculture, have also been reported [9]-[13]. TVWS, also known as super Wi-Fi, refers to the use of unused spectrum in Television bands. It ranges from 470 MHz -960MHz, and could be adopted as an alternative wireless platform for delivering both private and commercial services for wireless broadband and security network. A framework for the deployment of TVWS for the provision of wireless broadband in the rural area is shown in Fig. 1.

One of the major advantages of TVWS is its ability to travel over longer distances, through obstacles, tough and rough terrain than signals of higher frequencies, and consumes little power [14]-[15]. With its ability to travel over a long distance and penetrate obstacles, with abundant bandwidth, TVWS offers services that are extremely difficult for 3<sup>rd</sup> Generation of the mobile system and Wireless-Fidelity could not offer. To harness this potential, TVWS must be readily available. Of course, its availability will vary from one region to the other and is dependent on the terrain [16]. In this paper, the percentage

availability of TVWS in Ondo State radio vision-television station in Akure, south western Nigeria was evaluated and analyzed. Under the current traditional fixed spectrum allocation policy, TV spectrum licensed owners usually have exclusive access to certain portions of the spectrum. This policy as mentioned above has served well in the past, especially in the area of interference prevention among spectrum users. However, over the last two decades, with the proliferation of wireless services and applications coupled with the increase in demand for spectrum usage, fixed frequency allocation has been observed as the major problem of spectrum underutilization and spectrum scarcity. The main motivation of this research work is to address the spectrum utilization issue through measurement and evaluation of the available unused TV spectrum, whereby effective utilization rate can be achieved by introducing unlicensed users to access the under-utilized spectrum opportunistically.

## 2 Concept and Review of Related Studies

The available frequency may be detected using cognitive radio (CR) technology. CR is perceived as a technological advancement for efficient utilization of spectrum holes (known as white spaces). In this technique, unoccupied licensed spectrum bands are assigned to unlicensed users known as secondary users (SUs) without causing harmful interference or disturbance to the major occupant of the spectrum. The issue and concept of cognitive radio have several meanings from wide perspectives. It was first seen as an intelligent radio that senses its surroundings for operational electromagnetic and dynamically changes its behaviours to optimize user experience [17]. The cognitive radio cycle (see Fig. 2) involves spectrum sensing, spectrum decision, spectrum sharing, and spectrum hand-off. In Fig. 2, the spectrum sensing determines what portion of the spectrum is available as

well as detects the presence of spectrum licensed users and spectrum hole.

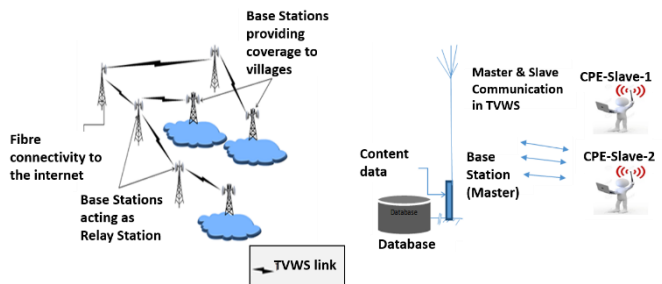


Fig. 1 TVWS for wireless broadband in rural areas [4].

The estimation of the available spectrum hole, obtained using spectrum sensing, is analyzed. The decision-making and learning part involves a scenario where cognitive radio determines the capacity of the channel, information on the spectrum hole data rate, and transmission bandwidth. Adaptation involves the ability of the radio spectrum to dynamically changes the functions according to its surrounding. During this stage, the CR can change the radio frequency, transmission power, modulation scheme, and communication protocol without any modification of the hardware environment.

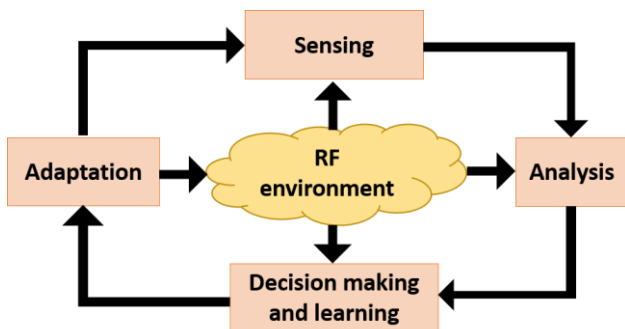


Fig. 2 Cognitive radio cycle [17].

One of the significant components of CR technology is dynamic spectrum sharing (DSA). DSA is a key enabling technology for the exploitation of spectrum holes in temporal and space domains to address both future and current spectrum scarcity in wireless networks [18]-[21]. A spectrum hole or white space is the frequency band in which a secondary user accesses a communication channel without interfering with any primary user. TV white space is the portion of the spectrum in the Very High Frequency (VHF) band between 30 –300 MHz and Ultra-High Frequency (UHF) band between 450 - 960 MHz that are not utilized by primary users (Television Broadcasting Stations) in specific time and location. Regulatory agencies such as FCC, NCC, and NBC prohibit the use of unlicensed devices in frequency bands allocated to TV stations, except for devices such as wireless microphones, remote control, and medical telemetry devices [22]. Currently, in Nigeria, TV broadcasting services mainly operate on analog transmission in the VHF spectrum band between 174 – 230 MHz and the UHF spectrum band between 470 and 960 MHz bands except for the TV stations that migrated to the digital broadcasting platform [23]. The transition from analog transmission to Digital Terrestrial Television (DTT) creates more spectrum opportunities for TV white space access and regulatory agencies of many countries had begun to explore this opportunity to address spectrum scarcity [24]. In Nigeria today, permissible frequencies of operation are between 470 to 694 MHz portions of the UHF band as determined by the

database for license-exempt master TVWS devices and 470 to 694 MHz portions of the UHF band for License-exempt client TVWS devices. Attard *et al.* [25] provide the occupancy rate of the spectrum band of 2.4 GHz using a cooperative sensing technique, with a combination of metrics such as AND, and OR on the measurement data to define the utilization of the spectrum. The low transmission power level results in the utilization of the spectrum being deeply dependent on the location of the measurement. Hoyhtya *et al.* [26] carried out a spectrum occupancy measurement in the 2.3-2.4 GHz band at Turku, Finland, and compared this to the situation in Chicago, USA. The researchers observed that there is a need for location-specific measurements in the 2.3-2.4 GHz band due to factors such as the limited transmission power of incumbent users in a location. In Patil *et al.* [27], spectrum occupancy measurement in Mumbai and Pune, India for 700 MHz-2.7GHz was carried out. The level of utilization of spectrum in the specified frequency bands in an outdoor area in the suburban of Mumbai, suitable for deploying cognitive radio technology was obtained. The results of this research indicated that the average utilization of the spectrum was found to be 6.62%. Adediran *et al.* [23] provide TV White Space in Nigeria in UHF band using a Geo-spatial approach. A map showing the concentration of the available radio spectrum within the country was provided. Faruk *et al.* [28] provide an algorithm for predicting DTV coverage, and protection contour estimation for spatial white space and DTV protection regions for spectrum sharing, respectively. Oluwafemi *et al.* [29] estimate and quantify the availability of television white space for broadband connectivity in southwestern Nigeria. The results obtained show that the pollution viewpoint approach will guarantee enough protection from the primary users and hence prevent interference from the secondary users. The findings also reveal that there are abundant TVWS in the considered states for the deployment of TVWS devices. Sarala *et al.* [30] use a strategy that depends on an adaptive threshold level to determine the spectrum in the energy detection method. It is useful to estimate the unoccupied spectrum when the noise is uncertain. It is obvious from these studies that research works on the quantification of spectrum occupancy level in Africa is limited, thus, this paper aims to evaluate and quantify the percentage availability of TVWS in Ondo State radio vision-television station in Akure, south western Nigeria.

### 3 Research Method

TVWS in a selected area in the capital city of Ondo state was quantified using both measurement and computational tools. This computational tool is used to determine the protection radius and the no-talk area from which a secondary user can harness and utilize the available unused TV spectrum. In order to have safe coexistence between the primary and secondary users (PUs and SUs), the incumbent TV service must be protected from excessive interference from the secondary transmitter. For such protection to be guaranteed, the SUs must be located outside the protection radius of the TV transmitter for a minimum distance (known as no talk distance) as described by the FCC [31]. Thus, it is necessary to estimate these parameters for the TV station. The protection radius is the maximum distance between the primary transmitter and the primary receiver when minimum sensitivity is maintained [32].

#### 3.1 Protection Point of View

The protection viewpoint is one of the methods that ensure the primary users are protected from interference from the

secondary devices. Protection enables license transmitters to operate in the band, which are allocated on a primary basis to the broadcast television service, on frequencies, and at locations where the spectrum is either not assigned to licensed services or not in use at particular times, while protecting primary users from receiving harmful interference. Thus, the protection radius  $r_p$  and the no-talk radius  $r_n$  are two important parameters to be estimated. The difference between the no-talk radius and the protection radius is calculated such that for any secondary device transmitting at  $r_n - r_p$  from the TV band receiver located at  $r_p$ , the SNR at the TV band receiver within a radius  $r_n$  does not fall below a threshold ( $\Delta$ ). Thus,

$$P_t + P_L(r_p) - N_o = \Delta \quad (1)$$

where  $P_t$  denotes the transmitter power,  $P_L$  is the path loss in (dB),  $r_p$  is the radius of protection,  $N_o$  is the thermal noise in dBm while  $\Delta$  is used to represent the threshold signal to interference noise ratio (SINR) in dBm. In Eq. (1), the thermal noise can be obtained using

$$N_o = 10 \log(KTB) \quad (2)$$

where  $K$  is the Boltzmann's constant,  $B$  is the bandwidth, and  $T$  is the noise temperature. The path loss  $P_L$  in Eq. (1) is obtained using the Hata's model expressed as

$$P_L(\text{dB}) = 69.55 + 26.16 \log f_c - 13.82 \log(h_b) - a(h_m) + (44.9 - 6.55 \log(h_b)) \log d \quad (3)$$

where  $f_c$  is the carrier frequency,  $h_b$  is the base station antenna height,  $d$  is the distance between the transmitter and the receiver and  $a(h_m)$  is the correction factor for the mobile antenna height expressed as

$$a(h_m) = 3.2 [\log(11.75 h_m)]^2 - 4.97, \quad f_c \geq 400 \text{ MHz} \quad (4)$$

The received signal level is obtained as

$$P_r = G_r G_t P_t \left( \frac{\lambda}{4\pi R} \right)^2 \quad (5)$$

The radius of protection is estimated using

$$r_p = (P_L)^{-1} \times (P_t - \Psi - N_o - \lambda) \quad (6)$$

where  $\Psi$  denotes the fading margin. The allowable interference level  $I_{rp}$  is the difference between the protection radius and the no talk radius  $r_n$ . Thus,  $I_{rp}$  is estimated from

$$I_{rp} = 10 \log_{10} \left( 10^{\frac{P_t - P_L - \Delta}{10}} - 10^{N_o} \right) \quad (7)$$

The difference between the protection radius and the no talk radius is related as

$$r_n - r_p = (L_o^{-1}) (P_s - I_{rp}) \quad (8)$$

In Eq. (8),  $P_s$  denotes the optimistic path loss of devices in TVWS determined by the interference threshold. Losses are 90% effective using the F50, 10 Model, Thus,

$$L_o = \left( \frac{90}{100} \times P_L \right) \quad (9)$$

Therefore, the no talk radius can be estimated as

$$r_n = (L_o^{-1}) (P_s - I_{rp}) + r_p \quad (10)$$

### 3.2 Study Area

The area under this study lies between Lat.: 7.30°N, Long.: 5.16°E. This area is a mixture of both residential and commercial buildings with enough vegetation. The estimated coverage area of the analysis network was obtained and calculated. Table 1 shows the parameters of the licensed TV station, their channels, and frequency of operation. The following parameters of the selected TV station are put into consideration;

- Latitude and longitude of the Transmitter.
- TV Transmission power.
- Frequency of operation.
- Antenna Height.

Table 1 Parameter of the selected TV station in Ondo State

Station	OSRC
Location	Ondo State
Geo location	Lat.: 7.30°N, Long.: 5.16°E
Channels	23 UHF
Carrier frequency	487.25 MHz
Transmitter power	40 kW
ERP	24 kW
Mast height	304.8 m
Transmitter antenna gain	31.70dBm
Receiver antenna gain	1.83

### 3.3 Spectral Analysis

The spectral analysis was done using a TinySA RF spectrum analyzer shown in Fig. 3. It is a handheld real-time spectrum analyzer that represents the magnitude of an input signal versus frequency in a graphical form within the full frequency range of the instrument. Fixed site monitoring was chosen for the analysis; one site was selected for the measurement.



Fig. 3 TinySA spectrum analyzer used for the measurement.



### 3.4 Measurement Set up

Scanning through the RF bands of TV channels for the various measurement locations was done using the RF spectrum Analyzer. The measurement setup and settings used were identical for all the locations. The spectrum occupancy measurement setup consists of a spectrum analyzer, storage device for data, and data manipulation equipment (laptop) as illustrated in Fig. 4. TinySA Handheld Touch Screen Spectrum Analyzer (displayed in Fig. 3), capable of measuring frequency range from 100 kHz to 960 MHz was used. This covers the frequency spectrum where TVWS is located. The device uses energy detection to directly measure the received signal level in dBm. It is also capable of displaying the spectrograph of signals. The analyzer has a USB interface for USB serial protocol. A 32 Gigabyte Storage device was used to save the log files generated by the spectrum analyzer in real-time so that they can be easily accessed through a laptop. The RF spectrum analyzer was connected to the laptop through a universal serial bus (USB) cable. The laptop aids in easy recording and capturing of the videos and pictures of the measurements taken and for their broader and quality display. To be able to execute the functions, RF Explorer windows software was installed on the laptop. The RF explorer spectrum analyzer has an inbuilt battery that is rechargeable. Also, a 30AH 12V DC power generator was used to ensure a steady supply of voltage to the laptop and RF spectrum analyzer.

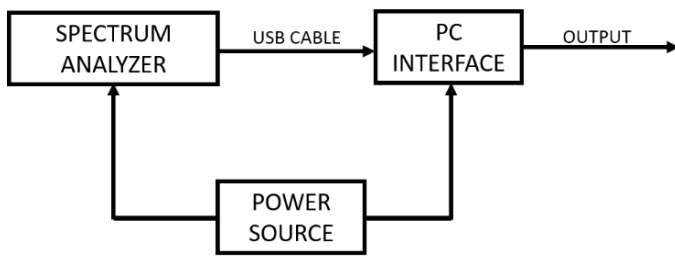


Fig. 4 The block diagram of the measurement setup.

## 4 Results and Discussions

### 4.1 Protection Radius and No Talk Radius

Table 2 shows some of the estimated parameters in the study area as well as some of the parameters used for the transmitting station. Using Fading Margin ( $\Psi$ ) of 1 dB (30dBm), Threshold/required SINR ( $\Delta$ ) of 15 dB (specified for 802.11g systems), and temperature of 301 °K as specified by the FCC [20], the thermal noise amounts to -135 dBm which is estimated using Eq. (2). The Effective Radiated Power (ERP) is converted to Effective Isotropic Radiated Power (EIRP) using ERP (dBm) + 2.15dB. Thus, a value of 75.95 dB is obtained as shown in Table 2. Using Hata's model described in Eq. (3), the estimated path loss amounts to 112.4 dB. The radius of protection using the protection perspective, with a fading margin of 1dB, with all values in linear, was estimated to be 72.05 km as shown in Table 2. Also, using a threshold SINR ( $\Delta$ ) of 15 dB, the allowable interference level was estimated to be -83.6 dB using Eq. (7), thus the no talk radius amounts to 74.06 km. The distance between the transmitter (Tx) and the receiver (Rx) (spectrum analyzer) at Okeodu, Akure is 1.4 km.

### 4.2 Spectral Occupancy Analysis

A spectral scan was done using a TinySA analyzer ranging from 470 MHz to 870 MHz with a span of 100 MHz. For more

realistic results, the frequency range was sectioned into four using the 100 MHz span. The first category was scanned between 470 MHz to 570 MHz. The second category range from 570 MHz to 670 MHz. The third and fourth categories range from 670 MHz to 770 MHz and 770 MHz to 870 MHz respectively. Table 3 shows the spectrum occupancy in the OkeOdu area of Akure while Fig. 5 illustrates the spectral plot for the 470-570 MHz frequency range.

Table 2 Parameters used for the location as well as the calculated parameters

Parameters	Value
Measured distance between the Tx and Rx	1.4 km
Effective isotropic radiated power (EIRP)	75.95 dBi
Estimated path loss	112.4dB
Receiver gain	0.1dB
Fading margin $\Psi$	1dB/30dBm
Thermal noise level ( $N_o$ )	-135 dBm
$P_r$	22.30dBm
$P_s$	120
Allowable interference level ( $I_p$ )	-83.6 dB
Protection radius ( $r_p$ )	72.05 km
No talk radius ( $r_n$ )	74.06 km

Table 3 Summary of 470-570MHz spectrum occupancy in OkeOdu, Akure.

S/N	Frequency range (MHz)	Spectrum occupancy
1	470 - 485.9	Unused
2	486 -492.78	Occupied (OSRC)
3	493.02 - 510	Unused
4	510 - 520	Unused
5	520 – 530	Unused
6	530 – 540	Unused
7	540 - 550	Unused
8	550 - 560	Unused
9	560 - 570	Unused

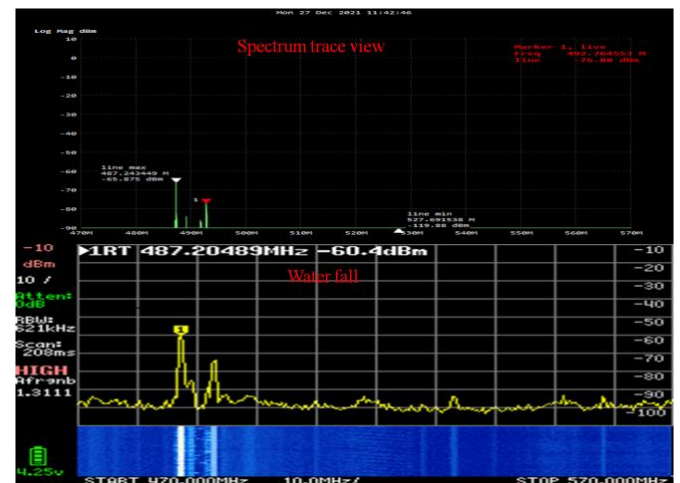


Fig. 5 Spectral analysis plot for frequency span 470MHz - 570MHz.

From Table 4, it is observed that a total number of nine channels were within the 470 – 570MHz frequency range. Out of these, only one channel was occupied while a total number of eight channels were unoccupied which can be referred to as white space. This simply means that about 88.9% of the channels are unoccupied in the range of 470 MHz – 570 MHz. This value indicates the percentage availability of TVWS within the frequency range. In Fig. 5, the spectral trace view and the waterfall history for the frequency range are presented. The white trace on the waterfall history as well as the green trace on the spectral trace view shows that OSRC occupied the frequency band between 486 MHz to 492.78 MHz. Table 4 and Fig. 6 show the spectral occupancy and the spectral analysis plot for the 570-670 MHz frequency spectrum in the study area. Considering Table 4, it is observed that a total number of 10 channels was within the 570 – 670 MHz range. In a similar manner to the results presented in Table 4 and Fig. 5, only one channel was occupied which was unknown while a total number of nine channels were unoccupied (white space). This simply means that 90% of the channels are unoccupied in the range of 570 MHz – 670 MHz while about 10% were already in use. The spectral trace view and the waterfall history for the 570 MHz – 670 MHz frequency range are presented in Fig. 6. The white trace on the waterfall history as well as the green trace on the spectral trace view shows an unknown signal occupying the frequency band between 651.37 MHz - 658 MHz.

Table 4 Summary of 570-670MHz spectrum occupancy in OkeOdu, Akure.

S/N	Frequency range (MHz)	Spectrum occupancy
1	570 - 580	Unused
2	580 -590	Unused
3	590 - 600	Unused
4	610 - 620	Unused
5	620 – 630	Unused
6	630 – 640	Unused
7	640 - 650	Unused
8	651.37 - 658	Occupied
9	659 - 660	Unused
10	660 - 670	Unused

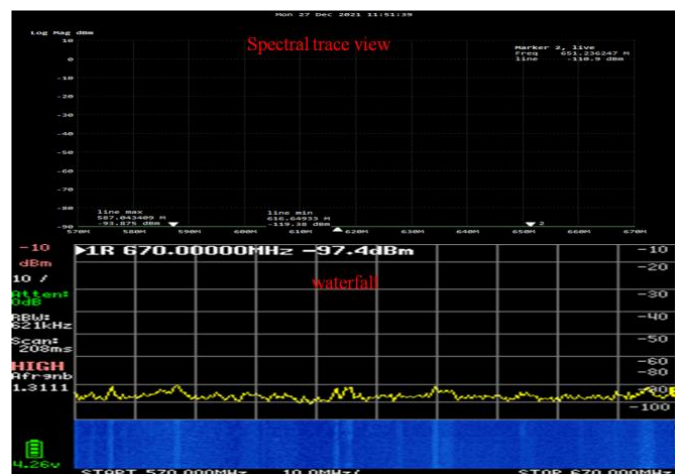


Fig. 6 Spectral analysis plot for frequency span 570MHz - 670MHz.

The results of the spectral scan for the 670-770 MHz frequency range are illustrated in Table 5 and Fig. 7 respectively. Table 5 shows the results from the spectral analysis carried out for 670 MHz to 770 MHz. It is observed that a total number of eight channels was within the 670 – 770MHz range. A total of four channels were occupied. Out of these channels, three were occupied by an unknown occupant while the remaining one was occupied by a GSM network.

Table 5 Summary of 670-770MHz spectrum occupancy in OkeOdu, Akure.

S/N	Frequency range (MHz)	Spectrum occupancy
1	670 - 670.9	Unused
2	671.98 -678	Occupied (unknown)
3	679 - 718.90	Unused
4	719.98 - 727.01	Occupied (unknown)
5	728 – 750.13	Unused
6	751.4 – 756.36	Occupied (unknown)
7	757 - 765.85	Unused
8	766 - 770	Occupied(GSM)

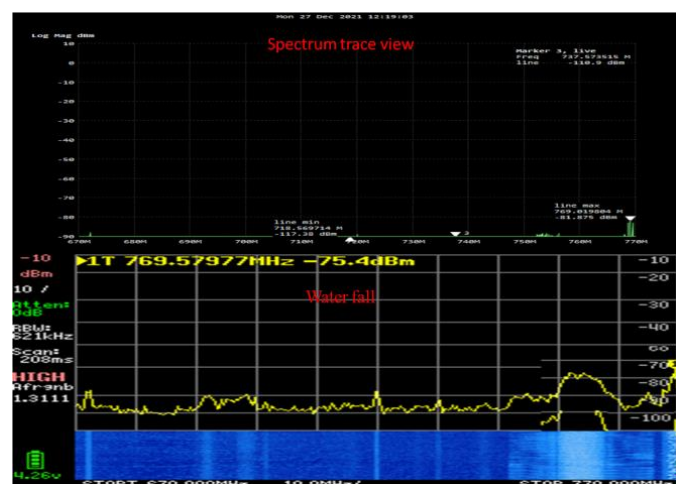


Fig. 7 Spectral analysis plot for frequency span 670MHz - 770MHz.

Table 6 Summary of 770-870MHz spectrum occupancy in OkeOdu,Akure.

S/N	Frequency range (MHz)	Spectrum occupancy
1	770 - 780	Occupied
2	780 - 790	Occupied
3	790- 810	Occupied
4	811 – 815.9	Unused
5	816.14	Occupied
6	817 – 830	Unused
7	830 - 840	Unused
8	840 - 850	Unused
9	850 – 862.9	Unused
10	863.99	Occupied
11	864 - 870	Unused

Also, it is observed that four of the channels were unoccupied (white space). From this, it can be seen that about 50% of the channels are unoccupied in the range of 670 MHz – 770 MHz. Fig. 7 shows the spectral trace view and the waterfall history for the frequency range. The white trace on the waterfall history as well as the green trace on the spectral trace view shows an unknown signal occupying the frequency band between 671.98 to 678 MHz, 719.98 to 727.01 MHz, 751.14 to 756.36 MHz while 766 to 770 MHz was occupied by a GSM network. The results of the spectral scan for the 770-870 MHz frequency range are illustrated in Table 6 and Fig. 7 respectively. Table 6 shows the results from the spectral analysis carried out for 770 MHz to 870 MHz. It is observed that a total number of 11 channels was within the 770 – 870 MHz range. A total of 5 channels were occupied by a GSM network while 6 channels were unoccupied. This means that the percentage availability of TVWS within the frequency range amounts to 55%. Fig. 8 shows the spectral trace view and the waterfall history. The white trace on the waterfall history as well as the green trace on the spectral trace view shows the occupancy signal of a GSM network.

Table 7 A summary of the analysis obtained from the readings.

Description	Value
Total number of channels	38
Number of channels occupied	11
Number of unoccupied channels	27
Percentage of occupied channel	28.95%
Percentage of unoccupied channel	71.05%

It is important to mention that from the readings taken at the study site, channel activity was detected at a noise level of (-135dBm). Analog TV signals were detected, as well as low power signals from distant transmitters. Table 7 shows the summary of the analysis obtained from the readings.

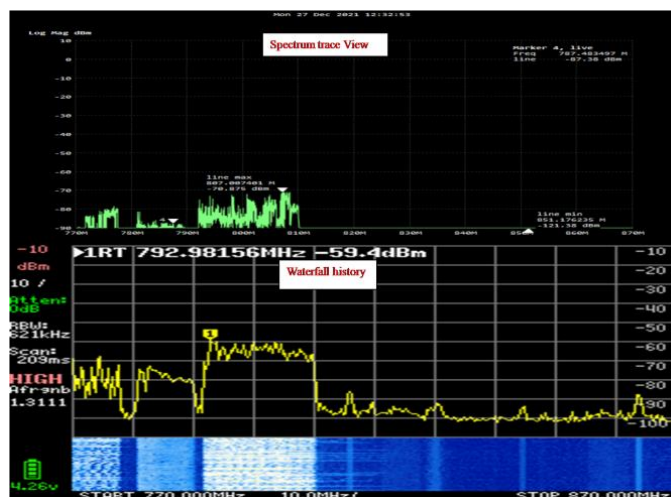


Fig. 8 Spectral analysis plot for frequency span 770MHz - 870MHz.

From Table 7, it can be seen that out of a total of 38 channels scanned within the 470 to 870 MHz frequency spectrum, only 11 channels which correspond to 28% of the total available spectrum were in use. Unfortunately, about 27 channels corresponding to almost 71.05% of the available channels were not in use. This clearly shows that the level of underutilization of the frequency spectrum is quite high. The underutilized channels

can be utilized by TV White Space devices. Fig. 9 shows the percentage spectral occupancy level within the 470 to 870 MHz in the study site. The analysis shows that there is an abundance of free spectrum within the 470 to 670 MHz range as shown in Fig. 8, which can be utilized for security surveillance as well as internet broadband.

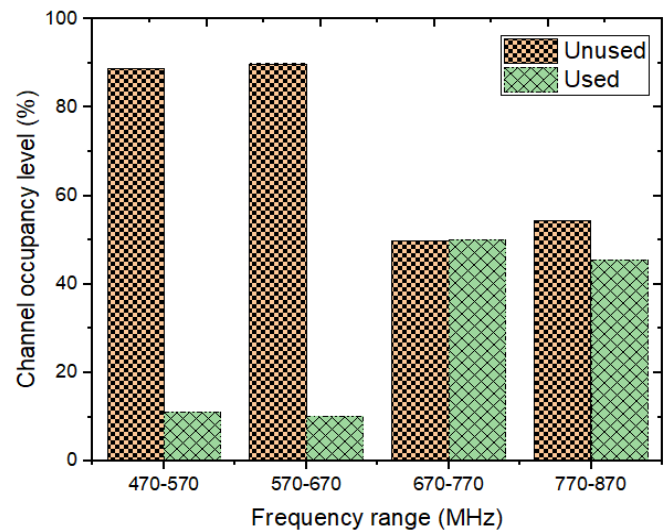


Fig. 9 Spectral occupancy level for the study area.

## 5 Conclusion

This study evaluates the availability of TVWS in Ondo State radio vision-television station in Akure, south western Nigeria. Outdoor spectrum measurement was carried out in the frequency bands of the licensed networks ranging from 470 MHz – 960MHz. The results obtained show that the rate of underutilization of the available spectrum is quite high. Out of a total of 38 channels within the frequency spectrum of interest, about 71.05% of the available channels are unused, while only 28.95% are in use. The rate of spectrum occupancy was discovered to be very low, thus giving room for unused spectrum spaces in the UHF frequency band which can be used to provide security surveillance. The percentage availability of TVWS will in turn open more bandwidth within the UHF band. The analysis also shows that there is an abundance of free spectrum within the 470 to 670 MHz range which can be utilized for security surveillance as well as internet broadband. The provision of security surveillance that will use TV White spaces in fighting crimes is of high essential in Nigeria today. It is also of importance that the unused spectrum that is available can be effectively utilized by introducing spectrum trading which will in turn be a win-win situation for those holding the license and are not using it to trade their license.

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