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Development of an algorithm for estimation of downlink co-channel interference level in a TV white space

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Abstract
The frequencies that are suitable for radio communication are a scarce resource and some of the licensed frequency bands are considered to be underexploited. The future visions comprehend using the spectrum more efficiently, but avoiding the interferences by means of cognitive radios. This paper discussed the estimation of downlink co-channel interference level of the detected secondary users of TVWS with primary users. In this paper, the empirical path loss model for Mgbakwu and its environment in Anambra State, Eastern region of Nigeria was developed, algorithm for detection of TVWS BS locations was also formulated and finally interference mitigation technique and co-channel interference estimation for TVWS using formulated algorithm and obtained dataset was designed. A Matlab function was developed to estimate the co-channel interference level of the detected secondary TVWS locations so as to determine the usable channels. The results obtained showed that with the deployment of the developed algorithm for TVWS location detection and interference mitigation, the performance of the system improved with respect to the signal strength obtained. At a distance of 400m, the signal strength of the model without co-channel interference estimation was 45dBm, while that of the developed model was 60dBm, this shows that there was 33.3% improvement in signal level and, the number of active subscribers connected during the simulation decreased as the distance increases. The developed model had 168 subscribers, while that of the model without interference mitigation had 50 active subscribers. This represents a 236% improvement and addition of subscribers.

Keywords: Spectrum, TV White Space (TVWS), Frequency, Interference, channel

1. Introduction

Current and future wireless communication systems require higher spectral usage due to increasing demand in user data rate. One of the principal techniques for efficient spectral usage is to implement a dense spectral reuse of the available radio spectrum. This can cause severe co-channel interference, and can hamper the system performance. In this work, the reuse of the Television (TV) spectra was characterized and the co-channel interferences detected were minimized which led to the increased usage of the white spaces by the local communities of Mgbakwu. TV signals rarely occupy the full spectrum allocated to them. In many regions, the subsequent white spaces between channels could be used by other communication devices. The high transmission powers and poor tolerance for co-channel interference makes the channel reuse factor very high for the broadcasting system. These unused spectra could be exploited in a dynamic manner by a secondary spectrum access technology, Television White Space (TVWS) systems, by adapting its transmission parameters to the environment without causing harmful interference to the licensed (primary) users of the band. These wireless technologies rely on the Cognitive Radios (CR). TVWS refers to as unused portions of spectrum in the TV bands and some channels which were not occupied after the transition from analogue to digital TV broadcasting (Maheshwari 2014).

The TVWS devices have the flexibility to sense, operate and latch on to unused TVWS channels. This is achievable with the use of a database that houses unused channels called geo-location database technology. The systems operating in the TV bands are analogue TV with sensitivity value of -94 dBm, digital TV with sensitivity of -116 dBm and wireless microphone with -107 dBm (Faruk et al 2013). In this regard, Federal Communications Commission (FCC) in the United States of America (USA) announced a threshold of -114 dBm as the criteria for TVWS (FCC 2008). The logic behind this was to make use of the unused spectrum of the incumbent systems for secondary access so that white space devices with low power could utilize this spectrum without causing interference with the incumbent systems.

In the paper presented by Thakur et al (2020), the possibility of co-channel secondary transmission over the operational Digital Terrestrial Video (DTV) broadcast bands within the interference limits of the DTV receivers was investigated. Aided by emulated DTV transmission experiments, secondary transmission-caused interference to the DTV receiver was analyzed. Using this understanding of interference behaviour, a new transmission scheme for the secondary network nodes was developed. The study was expected to serve as a valuable planning tool in deploying cognitive secondary networks over DTV transmission bands.

Saha (2016) presented a set of candidate regulatory requirements for TV Band Devices (TVBDs) in the Republic of Korea. To guarantee the protection of incumbent services, especially Digital Terrestrial Video (DTV) and wireless microphones, in TV frequency bands, minimum separation distances of TVBDs from the noise-limited contour according to incumbent users and TVBD types was considered. The author also dealt with multiple sets of separation distances of a co-channel TVBD network from a DTV protected contour on the basis of the radio propagation characteristics of different geographic areas to make good use of TV white space (TVWS) and safely protect the DTV service. The work presented a low-power transmission mode of TVBDs and the relevant separation distances for small-cell deployment. The TVWS field verification results, conducted on the island of Jeju in the Republic of Korea showed that incumbent services operate well without harmful interference from neighbouring TVBDs with the proposed separation distances.

In the work done by Hessar and Roy (2014), they explored the capacity of white space networks by developing a detailed model that included all the major variables, and was in cognisant of FCC regulations that provide constraints on incumbent protection. Real terrain information and propagation models for the primary broadcaster and adjacent channel interference from TV transmitters were included to estimate their impact on achievable WS capacity. The model was later used to explore various trades-offs between network capacity and system parameters and suggested possible amendments to FCC's incumbent protection rules in the favour of furthering white space capacity. The model described how secondary network capacity depends on TVBD system parameters such as power, antenna height, and device type and also on FCC protection regulations.

The works by other researchers relied on the ability of the cognitive radio to sense and detect the presence of primary users and also the use of geo-location database to minimize interference occurrence. This work has provided an additional technique using an algorithm to best situate secondary stations during network planning to further mitigate the chances of co-channel interference. This work was therefore aimed at developing an algorithm for estimation of downlink co-channel interference level in a TV White Space network.

1.1 Different Interference Cases in the White Space Operation

Four different types of interfering cases can be distinguished: the co-channel interference; the adjacent channel interference, blocking and receiver front end overloading. Receiver Front end overloading is referred to as a situation where strong signal in the adjacent channel makes the receiver to lose its ability to discriminate against the interfering signals at frequencies different than the wanted signal frequency.

The White Space Base Station (WSBS) is a fixed transceiver communication station that connects the Customer Premises Equipment (CPE) to the network. This WSBS can cause co-channel interference to the Digital Terrestrial Television (DTT) receiver’s if the guard distance to the nearest co-channel contour is too short in relation to the transmission power and the antenna height. The Adjacent Channel Interference (ACI) does not seem very likely inside the contour. If it is assumed that the fixed white space base station cannot use the first adjacent channel inside the contour, then the emission mask of the transmitter and the propagation loss should attenuate the signal to a sufficiently low level. This assumption should be valid in the case of fixed/access device since the FCC regulations prohibit the use of adjacent channel and the ECC regulations lead to low transmission power that the adjacent channel usage is practically impossible for the fixed/access device. Outside the contour, the first adjacent channel interference is possible near the TV contour edge which leads to a safety distance in the use of first adjacent channel also. The uplink interference in the white space base station means that the high power DTT transmitters cause co-channel or adjacent channel interferences, blocking or overloading to the base station when it is in the receiving state. The adjacent channel interference, blocking and overloading are possible if the transmitter is in the near vicinity and possibly in the same mast with the DTT transmitter.

Blocking and overloading depend on the distance of base station to the DTT transmitter but also on the white space base station properties. These problems might be possible especially with devices designed for the whole 470-790 MHz band since the selectivity can suffer because of the wide operation region. The co-channel interference from the DTT transmitters is very likely due to the high effective antenna heights of the TV transmitters (300-500m) and high transmission powers (80 dBm). With the base station antenna heights for example 50 – 100 m, this can result in high co-channel interferences to many of the seemingly unoccupied channels in the region. In the downlink direction, CPE acts as a receiver and can be interfered with by the DTT transmitters. Since the DTT network is designed for receiver heights of 10 m the co-channel and adjacent channel interferences are not very likely to occur. Blocking and overloading on the other hand are possible. When using the second adjacent channel and operating near the DTT transmission mast, the DTT signal is strong enough to cause blocking or even overloading. In the uplink direction the CPE is unlikely to cause co-channel interference. The guard distance of the base station is in most cases so large that it exceeds the CPE guard distance. Adjacent channel interference, blocking and overloading are however possible. This is due to the fact that the CPE antenna may be positioned in the near vicinity of the DTT receiver that is in the same roof perhaps with around 5 – 10 m distance to DTT receiver. In Table 1 is presented all the mentioned interference cases in fixed white space network and fixed DTT receivers.

Table 1: Summary of different interference cases in fixed white space network (Niskanen 2012)

Interferer	Victim	Reason	Importance
WS BS	DTT Rx	Co-channel	High
WS BS	DTT Rx	ACI	medium
WS BS	DTT Rx	Blocking	Low
WS BS	DTT Rx	Overloading	Low
DTT Tx	WS BS	Co-channel	High
DTT Tx	WS BS	ACI	medium
DTT Tx	WS BS	Blocking	medium
DTT Tx	WS BS	Overloading	low
WS CPE	DTT Rx	Co-channel	low
WS CPE	DTT Rx	ACI	high
WS CPE	DTT Rx	Blocking	high
WS CPE	DTT Rx	Overloading	high
DTT Tx	WS CPE	Co-channel	low
DTT Tx	WS CPE	ACI	Low
DTT Tx	WS CPE	Blocking	Medium
DTT Tx	WS CPE	Overloading	Medium

The **Importance** field in Table 1 demonstrates how important the said interference scenario is in the planning of the network. High means the interference cases that are reasonable to calculate and evaluate in all cases. The illustration of high interference cases is shown in figure 1.

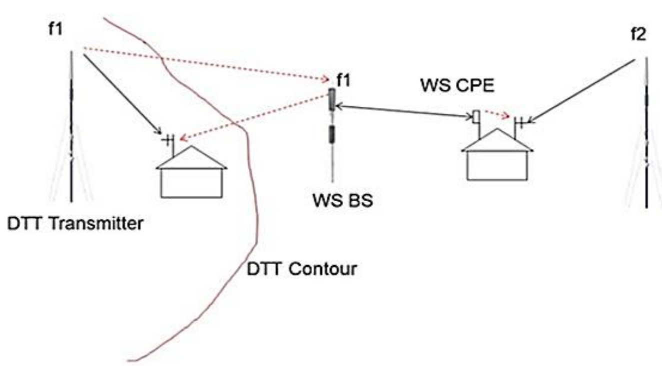

Figure 1: The high importance interference cases in the fixed white space network, assuming only fixed DTT reception (Niskanen 2012)

All the other high importance interference cases are co-channel interferences, but the DTT receiver next to white space CPE can suffer from three different interference cases shown in figure 2.

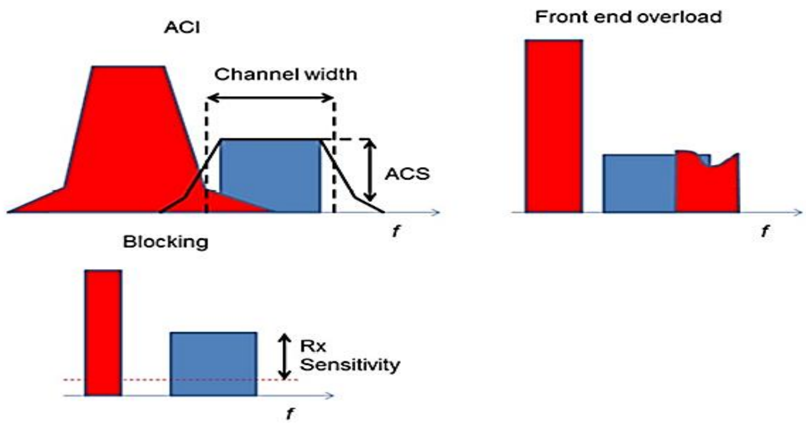

Figure 2: Different interference cases for the DTT receiver near the white space CPE (Niskanen 2012)

Besides the high importance interference scenario, medium scenarios are the ones that are possible, but demands right kind of circumstances so to speak. Such scenarios could be for example that white space base station is in the same mast with the DTT transmitter. Low importance scenarios are the ones that could not be possible if the regulations are obeyed.

2.0 Material and methods

2.1 Measurement environment considered.

Measurements were carried out in Mgbakwu/Isu(Awka rural) area in Anambra State. Figure 3 shows the Google map location of the measurement site. Table 2 shows the coordinate of the measured locations.

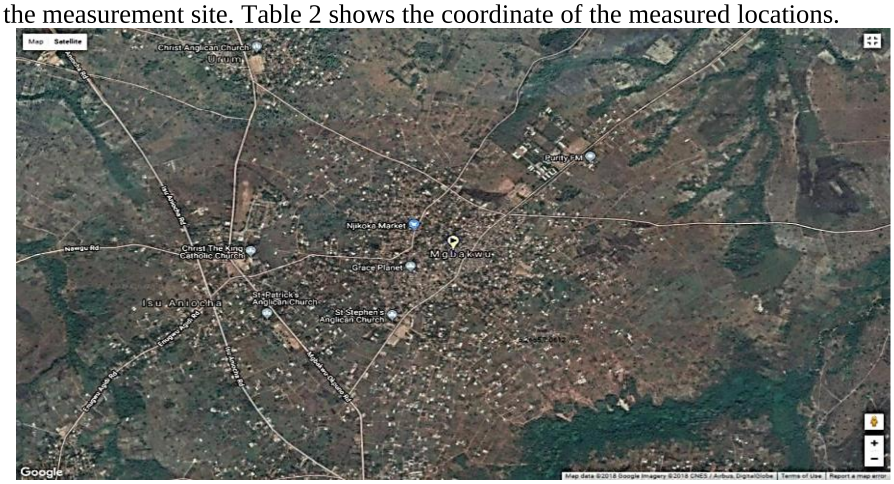

Figure 3: Google map of Mgbakwu

Table 2: Coordinate of the measured locations

Site Name	Latitude	Longitude
Mgbakwu	6.349273	7.115234
Isu	6.251504	7.026842

<u>2.1.1 National Broadcasting Commission (NBC) Licensed Stations in Anambra State</u>

Table 3 shows the licensed TV station signal, their channels and frequency of operation that can be received within the study area.

Table 3: TV Stations and their operating frequencies in Anambra State

S/No	STATION	CHANNEL	FREQUENCY
1.	NTA Onitsha	35	583.25MHz
2.	Anambra Broadcasting Service (ABS)	27	519.25MHz
3.	Silverbird Television	30	543.25MHz
4.	Minaj Broadcasting International (MBI) Anambra	41	631.10MHz

2.1.1.1 Measuring instruments/equipment

1. A laptop equipped with touchstone RF spectrum Analyzer software.
2. Spectrum Analyzer (Rf explorer 3G combo model)
3. Mini USB cable.
4. A Samsung Tablet equipped with global positioning system (GPS) application.

2.1.1.2 Measurements and data collection

The Radio Frequency (RF) Explorer 3G combo model was used for the measurement. The RF Explorer was connected to window Personal Computer (PC) through the Universal Serial Bus (USB) port for better visibility and other functionalities such as high-resolution view, save screen shot image, print data and export to Comma-Separated Value (CSV) file for use in 3rd party tools such as excel (RF Explorer spectrum Analyzer user manual, 2017).

Readings were taken using the spectrum analyzer to measure the received signal strength for all the 50 UHF channels (21 through 70) corresponding to 470 – 870 MHz with an Omni-directional antenna attached to the analyzer, a personal computer (laptop) and a GPS device for over 60 sweeps. This was repeated every one hour over twenty-four-hour duration. The RF explorer antenna height was stationed on a stand 1.5 meters above the ground, a span of 100MHz was used to enhance the visibility of the spectrum measured and the resolution bandwidth in the experiments was set to 178.57 KHz on the RF Explorer window client. Measurements using RF explorer revealed that the ambient noise level in the absence of any transmission channel occupied by a primary user is -108 to -115dbm. This was confirmed through repeated measurements in a known vacant channel at 24:00hrs when the station considered normally ends transmission (i.e Silver bird that transmit on 543.25MHz). Keeping sufficient cushion for low power transmission, -110dbm was chosen as the noise threshold for the measurement.

It is a well-known fact that the altitude of a place of the base station is an important factor in determining the coverage area and the end user throughput. But using just the geographic radio coverage area as a metric for TVWS antenna placement can lead to placing an antenna at a place with a high altitude and high coverage radius, but a low population being served around it. Therefore, coverage area by itself is not a good metric since it does not consider the population of the places within its coverage. On the other hand, selecting a place for TVWS antenna based on population alone is also not a good idea since it may be the case that the place has a high population but a very low altitude, requiring many base stations. As a consequence, a metric called the weighted utility was defined, which considers both the coverage area and population while determining the places to be selected as TVWS transmitters. This metric ensures that the place selected for TVWS deployment has a proper balance between the coverage area and the population it serves. The formula for weighted utility is as follows:

$$WeightedUtility \longleftarrow \frac{Users^2[d_1] \times U[d_1] + \cdots + Users^2[d_n] \times U[d_n]}{User[d_1] + \cdots + User[d_n]} \qquad (1)$$

where

$U[d_n]$= value of utility function at ‘n’ km distance

$User[d_n]$ = number of people within ‘n’ km from a place

The utility function is defined by the following equation:

$$U[d_n] \leftarrow \frac{Throughputatdistance^{'d_n'}}{Bandwidthrequiredperuser \times No.\times ofuserswithin^{'d_n'}} \tag{2}$$

In the calculation of utility function, the throughputs obtained at each of the locations which are within the coverage radius of a potential TVWS antenna were considered. The throughput was then divided by the total bandwidth requirement of the population within that region. In this way, both the coverage area and population were considered while calculating the utility function. In order to give more weight to those places having a higher population, a weighted value of the utility function was taken and included while calculating the weighted utility metric.

A theoretical model based on Shannon's theory was used to calculate the throughput at any distance. The throughput T_p at distance d_n is calculated as follows:

$$T_p[d_n] = B_w \times log_2\left(1 + \frac{S[d_n]}{N}\right) \tag{3}$$

$$S[d_n] = P_{transmit} - L_p[d_n] \tag{4}$$

Where,
$T_p[d_n]$ = throughput at distance of 'dn' km (Mbps)
B_w = channel bandwidth (MHz)
$S[d_n]$ = signal at distance of 'dn' km (Watts)
$P_{transmit}$= Transmit Power (dBm)
L_p = Path loss at distance of 'dn' km (dBm)
N = thermal noise (Watts)

The path loss affects the utility inversely. This is because as the path loss increases, the throughput decreases, and since the utility is directly proportional to the throughput, therefore the utility decreases with the increase in path loss. Radio propagation models are the crucial tools in a national terrestrial broadcast TV planning model. The models are used to predict the worst-case scenarios for path losses, the received signal power or field strength at the receiver. Generally, radio propagation models are categorized according to their specific usage and a suitable model must be selected for each planning scenario.

2.2 Empirical path loss model for the test bed

The propagation path between the transmitter and the receiver may vary from BS to BS and from simple line-of-sight (LOS) to very complex one due to diffraction, reflecting and scattering resulting from either natural or constructed obstacles (Saha 2016). For Such environments, the propagation path may be modelled as a randomly varying propagation path and in many instances; there exist more than one propagation path leading to multipath propagation. Such environments are characterized by fading effects such as: shadowing, multipath fading and path loss. These fading effects are best described (in a large scale) by the path loss exponent which defines the rate of change of attenuation that the signals suffer as it propagates from the transmitter to the receiver. The average large-scale path loss for an arbitrary transmitter to receiver separation is expressed as a function of distance as (Jari 2010):

$$\mathrm{P_L(dB)} = \mathrm{P_L(d_0)} + 10\eta\mathrm{Log}\left(\frac{\mathrm{d}}{\mathrm{d_0}}\right) \tag{5}$$

Where: $\mathrm{P_L(d_o)}$ is the estimated path loss at reference distance $\mathrm{d_0}$, η is the path loss exponent and d are the distance between MS and BS. It was shown by Erceg et al, (1999) that for any value of distance *d*, the path loss $\mathrm{P_L(dB)}$is a random variable with a log-normal distribution about the mean value due to shadowing effect. To compensate for shadow fading, the path loss beyond the reference distance can be written as:

$$\mathrm{P_L(dB)} = \mathrm{P_L(d_0)} + 10\eta\mathrm{Log}\left(\frac{\mathrm{d}}{\mathrm{d_0}}\right) + \varsigma \tag{6}$$

Where ς is the shadowing factor and also a Gaussian random variable (with values in dB) and modelled as log normal with zero mean and standard deviation σ (also in dB). The standard deviation of the shadowing factor is known as the location variability.
The standard deviation is given as (Erceg et al, 1999):

$$\sigma = \sqrt{\sum \frac{(P_L(d_i) - P_L(d_0))^2}{N}} \quad (7)$$

Where $P_L(d_i)$ is the measured path loss at distance, d_i, $P_L(d_o)$is the estimated path loss using equation 5.0, N is the number of measured data points.
The path loss exponent η, is obtained from measured data by applying the method of linear regression analysis (Azubogu et al, 2011) (or method of least squares) such that the sum of squared errors gives:

$$e(\eta) = \sum_{i=1}^{m} (P_L(d_i) - P_L(d_o))^2 \quad (8)$$

Making $P_L(d_o)$ in (5.0) the subject of formula and substituting into equation 8.0 gives:

$$e(\eta) = \sum_{i=1}^{m} (P_L(d_i) - P_L(d_0) - 10\eta \mathrm{Log}\left(\frac{d}{d_0}\right))^2 \quad (9)$$

The value of η which minimizes mean square error (MSE) can be obtained by equating the derivative of $e(\eta)$ to zero. Differentiating equation 9 with respect to η and equating to zero gives:

$$\frac{\delta e(\eta)}{\delta n} = -20\log\left(\frac{d}{d_0}\right)\sum_{i=1}^{m}\left(P_L(d_i) - P_L(d_0) - 10\eta \mathrm{Log}\left(\frac{d}{d_0}\right)\right) = 0$$

$$\sum_{i=1}^{m} (P_L(d_i) - P_L(d_0) - 10\eta \mathrm{Log}\left(\frac{d}{d_0}\right)) = 0$$

$$\sum_{i=1}^{m} (P_L(d_i) - P_L(d_o)) = \sum_{i=1}^{m} (10\eta \log_{10}(\frac{d_i}{d_o})$$

$$\sum_{i=1}^{m} (P_L(d_i) - P_L(d_o)) = \eta \sum_{i=1}^{m} (10 \log_{10}(\frac{d_i}{d_o})$$

Making η subject of formular gives:

$$\eta = \frac{\sum_{i=1}^{m} (P_L(d_i) - P_L(d_o))}{\sum_{i=1}^{m} (10\log_{10}(\frac{d_i}{d_o}))} \quad (10)$$

Where:
$P_L(d_i)$is the average path loss which is the difference between the transmitting power (P_t) in dB and received power (P_r) in dBm,
$P_L(d_o)$= the path loss at close-in reference distance otherwise known as reference path loss,
$d_o$is close in reference distance,
d_i is distance at intervals from the BS to MS.
The pathloss exponent for the test bed can be calculated using equation 10.

2.3 Formulation of Algorithm for Detection of TVWS BS Locations

This work adopts a greedy algorithm approach for detecting secondary TVWS locations and computes their weighted average throughputs.

Algorithm: Greedy algorithm approach for detecting secondary TVWS locations

Input: Place, population, latitude, longitude, altitude, bandwidth requirement per user
Output: Secondary transmitter locations, weighted average throughputs
begin

1 **Calculate** the coverage radius $\mathfrak{R}$ based on the altitude.
2 **Find** all the locations and the distances of those locations which fall within its coverage radius.
3 **For** computed $\mathfrak{R}$
Using Eqs. 1.0, 2.0, 3.0, 5.0 and 10.0
Compute path loss, corresponding throughput, utility and weighted utility for all those distances where other locations are situated.
4 **For** (all the list of places), **Select** the place which has the highest weighted utility and cover all the locations present within its radius.
5 **Remove** the place which is selected as the secondary transmitter and the locations it covers from the list of places in the input.
6 **Repeat** the steps 5 and 6 till all the places given in the input are not covered.
7 **For** all the places which are selected for white space antenna placement and the locations they cover, run the propagation model again for calculating the path loss at all those distances where those locations are present.
8 **Find** the corresponding weighted average throughput for each place where the secondary antenna will be deployed.
9 **Return** weighted average throughput

End

2.4 **Interference mitigation technique for TVWS using formulated algorithm and obtained dataset**

In the white space case the DTT transmitters can cause interference to the white space network. The white space transmitters are not allowed to interfere with the DTT network because it is the licensed user of the band and its customers are paying for the interference free operation. The actual disturbance level that the data signal has to overcome is noise plus interference. The interference always raises the combined noise and interference level, but if the interference is small enough related to the noise level, the addition does not have any effect on the operation of the system. The DTT system causes interference to white space networks which has to be also considered in order to make fully functioning networks.

To estimate the co-channel interference a Matlab function was developed to estimate the interference level of the detected secondary TVWS locations so as to determine the usable channels. The co-channel interference was estimated by first abstracting the DTT networks into a stochastic geometry model. The interference power received by any WSD at arbitrary location was inferred based on a single power spectrum measurement taken at the base of the serving Base Station (BS). This was achieved by estimating the transmissions of neighbouring BSs, and inferring the resulting interference power at any point of interest. The system inferred the average channel quality at any random point, based on some passive measurements taken at a single observational point. The method was applied to opportunistic interference avoidance and the results demonstrate the accuracy of this technique for a variety of network configurations. The simulation results shown in section four demonstrated the methodology by showing how it avoided transmissions to channels which were overwhelmed by interference.

3.0 Results and discussion

3.1 Simulation

The data obtained from the test-bed location was used to carry out simulations to ascertain the performance of the developed system. The TVWS planning tool used was available online from the website https://www.cse.iitb.ac.in/~tvws/tvws_tool/Thane/client.html.The tool used for TVWS network deployment was integrated with Google Maps for displaying the location of secondary base stations. The sample output of the terrain using the planning tool is shown in figure 4. The list of places to be covered for planning TVWS deployment can be either selected by using import or auto-pick option. When the front-end interface was executed, PHP and MySQL scripts running at the back end determine the optimal locations for placing secondary white space antennas and display them on a Google Map as shown in figure 4. The simulation parameters chosen were standard values as contained in Table 4.

Table 4 Simulation Parameter

Parameter	Value
Environment type	Rural
TVWS frequency	470MHz – 770MHz
TVWS antenna height	7m – 30m
Secondary transmit power	Variable
Channel width	8MHz
Receiver sensitivity	-90dBm
Bandwidth required per user	0.5MHz

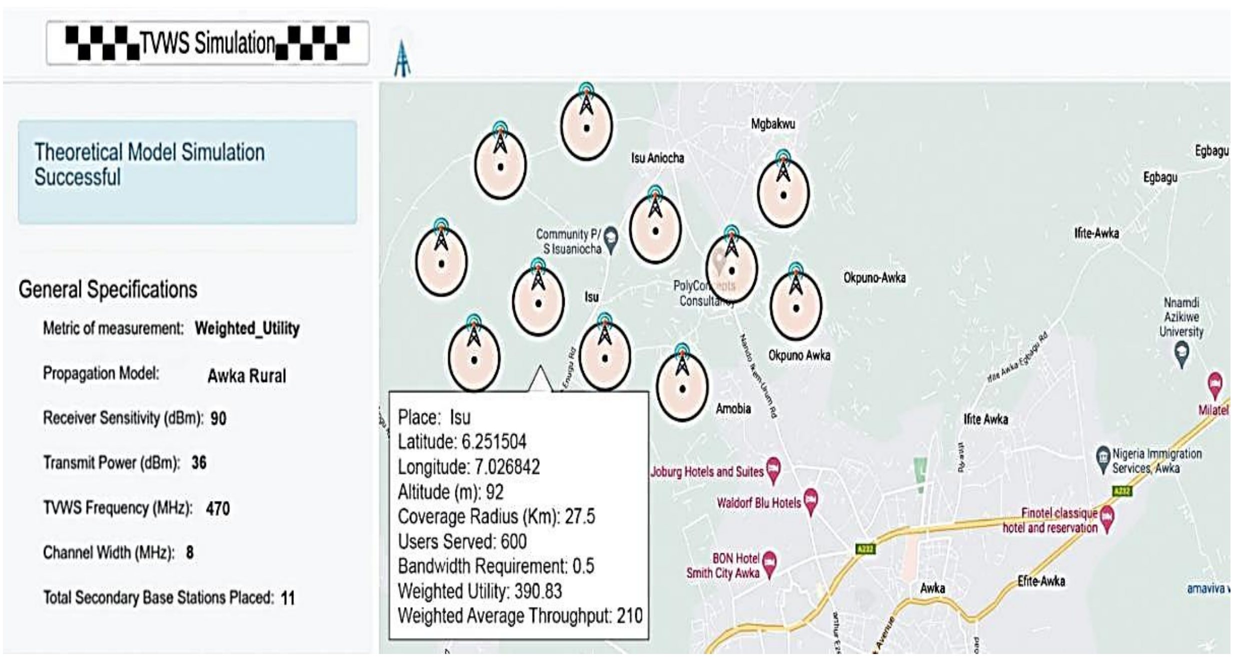

Figure 4: Simulation sample output from planning tool for Awka Rural

During the simulation, the interference estimation function goes through all the test points located by the TVWS tool one at a time, calculating the received signal strengths from every transmitter less than 4 Km away. It was assumed that the tall high power TV transmitters from ABS Awka would interfere with the white space base station antenna from several hundred of meters away and so the 4 km seemed the appropriate limit.

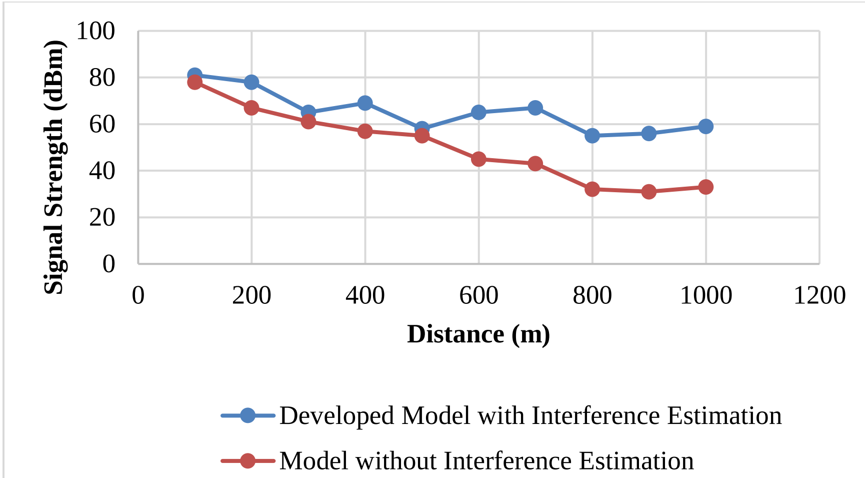

Figure 5: Behaviour of the WSD transmitter with the developed model

From figure 5, it is visible that with the deployment of the developed algorithm for TVWS location detection and interference mitigation, the performance of the system improved with respect to the signal strength obtained. When the distance extended beyond 450m, the significant drop of the field strength is highly noticeable from the model without interference estimation. At a distance of 600m, the signal strength of the model without interference estimation was 45dBm, while that of the developed model was 68dBm. This represents a 51.1% improvement.
Simulation results were also showcased to see the impact of interference from transmitters located at distances farther than 4000m from the WSD. The simulation result is as shown in figure 6.

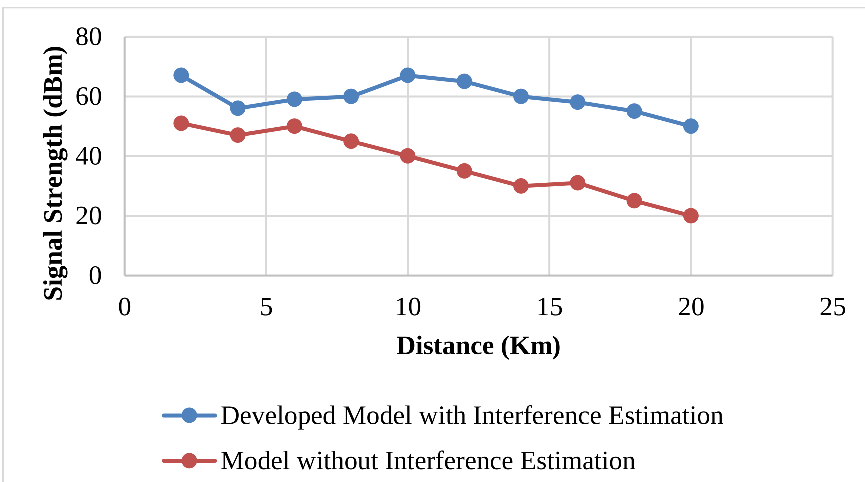

Figure 6: Behaviour of the WSD transmitter with the developed model for transmitters beyond 4km

From figure 6, it can be seen that with the deployment of the developed algorithm for TVWS location detection and interference mitigation, the performance of the system improved with respect to the signal strength obtained when the interference was coming from transmitters that are located from farther distances. When the distance extended beyond 4000m, the significant drop of the signal strength was highly noticeable from the model without interference estimation. At a distance of 10km, the signal strength of the model without channel estimation was 40dBm, while that of the developed model was 67dBm. This represents a 67.5% improvement.
The number of active subscribers connected during the simulation was also analyzed and presented in figure 7.

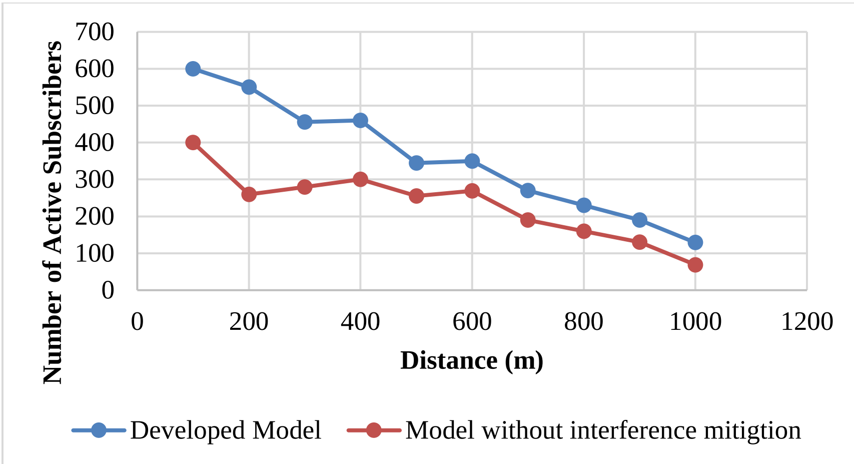

Figure 7: Number of Active subscribers

From figure 7, the number of active subscribers detected during the simulation was analyzed and the result showed that as the distance increased, the number of active subscribers decreased. The result obtained also showed that the developed model performed better when the interference mitigation technique was applied to the system. It can be seen from figure 10 that at a distance of 100m, the developed model had about 600 subscribers, while that of the model without interference mitigation had 400 active subscribers. This shows a 50% improvement and addition of subscribers. This is important because the placement of the WSD in a location where the interference effect was reduced due to the technique employed proved effective. It can also be seen from figure 7 that at a distance of 1000m, the developed model had about 129 subscribers, while that of the model without interference mitigation had 69 active subscribers. This represents a 86.95% improvement and addition of subscribers. Also, for the location area being considered, which Awka is, the overall signal strength of each WSD placed was estimated and shown in figure 8. This showed the measured signal strengths of the transmitters over 8 MHz wide channels as estimated by the developed model. A comparison was also done to compare the measured and the estimated values of the signal strength.

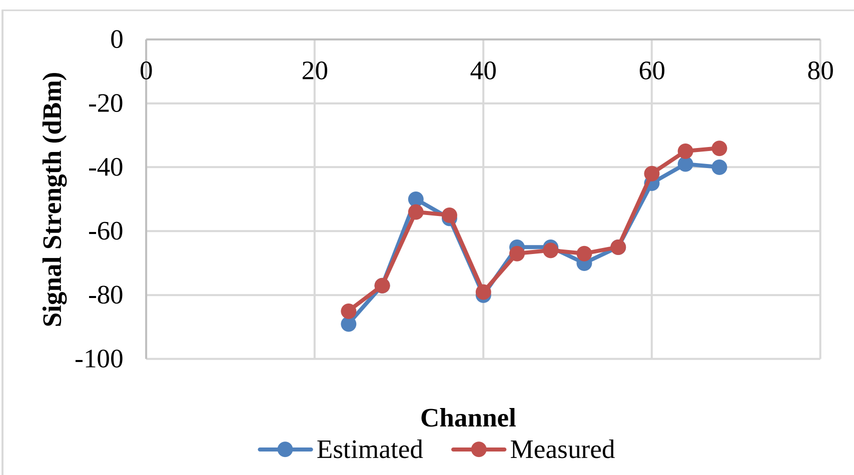

Figure 8: Measured signal strengths of the transmitters

From figure 8, it can be seen that the deviation of the measured value from the estimated value was not too obvious. This can be attributed to a lot of unforeseen features that could arise during the radio propagation.

4.0. Conclusion

The works by other researchers relied on the ability of the cognitive radio to sense and detect the presence of primary users and also the use of geo-location database to minimize interference occurrence. This work has provided an additional technique using an algorithm to best situate secondary stations during network planning to further mitigate the chances of co-channel interference. During the simulation for this work, the interference estimation function went through all the test points located by the TVWS tool one at a time, calculating the received signal strengths from every transmitter less than 4 Km away. Results showed that with the deployment of the developed algorithm for TVWS location detection and interference mitigation, the performance of the system improved with respect to the signal strength obtained. When the distance extended was beyond 450m, the significant drop of the field strength is highly noticeable from the model without interference estimation. At a distance of 600m, the signal strength of the model without channel estimation was 45dBm, while that of the developed model was 68dBm. This represents a 51.1% improvement. The number of active subscribers detected during the simulation was analyzed and the result showed that as the distance increased, the number of active subscribers decreased. The result obtained also showed that the developed model performed better when the interference mitigation technique was applied to the system. It can be seen from figure 10 that at a distance of 100m, the developed model had about 600 subscribers, while that of the model without interference mitigation had 400 active subscribers. This shows a 50% improvement and addition of subscribers. This is important because the placement of the WSD in a location where the interference effect was reduced due to the technique employed proved effective. It can also be seen from figure 10 that at a distance of 1000m, the developed model had 129 subscribers, while that of the model without interference mitigation had 69 active subscribers. This represents a 86.95% improvement and addition of subscribers.

The significance of the obtained result was revealed in the increased coverage as seen from the improved signal strength obtained and consequently improved active subscribers as the distances increases compared with the models without additional interference mitigation. This work developed an additional technique for planning a television white space network to further mitigate co-channel interference. This research could be helpful to operators in improving spectrum efficiency and facilitating the use of TV white space in providing cheap and affordable broadband connectivity especially in the rural areas and also attract more research interest in this area. Finally, it has been shown that the developed algorithm for secondary station location detection and placement of the WSD in such locations where the interference effect was reduced proved effective and makes for efficient use of TV white space with minimal co-channel interference to the incumbent users of the spectrum.

5.0 Recommendation

In future, a geo-location database interference mitigation system can be used for TVWS network estimation, planning and deployment. The collaboration of the two techniques such as geo-location database and co-channel interference mitigation system can perform more efficiently and can make system innovatory.

Nomenclature

B	-	Bandwidth in Hertz.
B_w	-	Channel bandwidth
ς	-	Shadowing factor
d_i	-	Distance at interval from Base Station to Mobile Station
d_o	-	Close in Reference Distance
$e(\eta)$	-	Sum of the squared errors
L_p	-	Path loss at distance of 'dn' kms
N	-	Thermal noise
η	-	Pathloss exponent
σ	-	Standard deviation
P_{n0}	-	Noise Power
$P_{transmit}$	-	Transmit Power
$P_L(d_o)$	-	Estimated path loss at reference distance d_0,
$P_L(dB)$	-	Path loss beyond reference distance
$P_L(d_i)$	-	Measured path loss at distance d_i,
P_t	-	Transmitting power
P_r	-	Received power
$S[d_n]$	-	Signal at distance of 'dn' kms
T_e	-	Temperature of the environment in Kelvin's
$T_p[d_n]$	-	Throughput at distance of 'dn' kms
$U[d_n]$	-	Value of utility function at 'n' kms distance
$User\ [d_n]$	-	Number of people within 'n' kms from a place

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