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On the Study of Interference Scenario on TV Broadcast and Wireless Systems for Emergency Communication Networks in TVWS

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Abstract: This paper investigated frequency sharing between primary TV systems (channels 32 and 49) and Emergency Communication Networks (ECNs). The networks to be implemented in the Osogbo axis of Osun State function on a secondary geographical basis, creating no harm to the original licensed primary TV viewers. A minimum separation distance of 41 dB was suggested as the protected contour for the UHF spectrum to oversee the protection of primary TV users for the UHF bands under consideration. The effects of changing the secondary systems' transmitting power, transmission frequency, and antenna height on the service coverage distance were also explored. The performance of the UHF band was evaluated when it was utilized for secondary transmission at both low and high transmitting powers, with the performance criterion being percentage coverage distance. This work complies with the International Telecommunication Union-Radio sector (ITU-R) recommendations of 16 dB for signal-to-noise ratio and 41 dB for signal strength. It can also be deduced from the result that when the transmission power of ECN devices is raised from 40 mW to 4 W, Effective Isotropic Radiated Power (EIRP) is used; it caused a 76.19% reduction in the coverage spacing for TV channels of ECN Network secondary devices. For the White Space Device (WSD) to operate in Temporal mode, the maximum allowable power (4 W) used in spatial mode should be replaced by a 76.19 per cent reduction. Additional sensing margins of 3.76 dB and 4.04 dB for channels 33 and 43 must be added to the FCC threshold limit of -114 dBm criterion for TV white spaces to assure ECN deployment without causing severe interference to TV customers.

Keywords: Effective isotropic radiated power, path-loss, signal strength, signal-to-noise-ratio, TV white space

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1. INTRODUCTION

Emergency communications have a crucial role in emergencies, serving as the nerve center for emergency rescue and stability maintenance of the victims. Disasters, accidents, public health incidents, social security crises, and other emergencies happen often [1].

The clash of social interests has grown more complex, emergencies have become more frequent, their impact and spread have expanded, and the likelihood of major wars has also increased as the international political and military environment has changed and as national reform and opening up have continued to deepen. The greater it gets, the more crucial it is to handle and control emergencies on-site quickly.

It is vital to push forward new guidelines for emergency communications at the emergency site and swiftly convert the combat effectiveness generation mode of the emergency response team. The importance of this research work is to utilize TVWS as an emergency communication network to cater for emergency needs and assist in calling the appropriate agency to respond promptly on time to emergencies, like a fire service agency for Fire-outbreak, security agency for robbery and other social menace problems, traffic agency for traffic congestion, ambulance agency for accident victims.

Therefore, free access to calls is needed without purchasing a network recharge card, as in the mobile communication network.

The interference scenario of the TV broadcast and wireless Emergency Communication Network (ECN) was further analyzed to close the gap of obstruction from interference that can hinder the smooth running of the ECN network [1].

Unoccupied frequency zones between licensed broadcast channels or wireless broadcast services such as wireless microphones are known as white spaces or spectrum gaps. Television White spaces (TVWS) are vacant frequency bands between occupied (licensed) broadcast television channels or broadcast auxiliary services like wireless microphones, there are white gaps, which are empty frequency bands. The FCC had to establish a frequency "guard bands" between television channels to prevent interference since analogue television receivers were extremely prone to interference [2].

Owing to the increasing number of spectrum requests resulting from network and wireless technology advancements, efficient spectrum utilization has become a critical task that must be accomplished for this purpose. Due to lower coverage costs, lower frequencies of less than 1 GHz, which are employed in the terrestrial broadcast service band, are of interest in the radio spectrum. Favorable coverage cost is the advantage when comparing frequencies below 1GHz (especially in a terrestrial broadcast band) to higher frequencies above the same limit when it is implemented for wireless services in mobile internet and Wireless-Fidelity (Wi-Fi) [3]. Radio researchers have studied television coverage analysis for white space usage from radio propagation and its applicability in various terrains [3].

In [4] investigation was carried out on the difficulties of spectrum detection in cognitive radio wireless and television broadcasts. Frequency agility operation, geo-location database, and capacity to provide reliable services in an empty spectrum are only a few obstacles.

In [5], the number of geo-location databases for main user protection and efficient spectrum hole usage was noticed through specific computational and implementation complexity reduction strategies.

In [6], it was learned that combining an optimized Single Frequency Network and a Hybrid Frequency Network design can result in a Digital Television network plan.

In [7], the genesis of TVWS from the digitization phase of TV transmission was explored. The detection, verification, and characterization of TVWS in India's National Capital Region were also emphasized. The application provides for the generalization of a spectrum graph based on the availability of white space in a map location retrieved from a secondary user application.

In [8], a certain focus was placed on the analogue to the digital switchover in the 470-790 MHz spectrum to allow for improved white space use. The channel model plays an essential part in analyzing the impact of the chosen propagation model on the result since the quantity of signal power from the secondary user varies over different channels when considering interference constraints.

The allocation range for VHF and UHF stations is shown in Table 1a, while the allocation for research workstations is shown in Table 1b.

Many nations worldwide have been testing and adopting White Space Devices (WSDs) that utilize Television White Space to improve the television radio spectrum (TVWS) utilization. Comparing the norms and laws governing TVWS in various nations, including Singapore, the United Kingdom, the United States, Japan, and the Philippines. Comparisons were made regarding some factors like the spectrum identification technique employed, the classes of their WSDs, the frequency range, bandwidth, transmit power, and operational safety criteria. Investors would be reassured of the stability. The future of the technology if rules for the usage of TVWS were set from the deduction of the comparison. Also, it has been reported that the commercialization and testing of TVWS to close gaps have varied applications [10].

Table 1a. UHF and VHF frequency allocation [9]

Frequency Spectrum	Band	Range	Service
VHF	I	(41-68) MHz	TV BAND I
VHF	II	(85.5-100) MHz	FM SOUND
VHF	III	(175-215) MHz	BAND III (TV)
UHF	IV	(470-582) MHz	BAND IV (TV)
UHF	V	(582-960) MHz	BAND V (TV)

Table 1b. UHF television bands parameters in Osun State

Television Stations	Centre Frequency (MHz)	Antenna height above sea level (m)	Transmitters Effective Radiated Power (kW)
NTA Osogbo, Channel 49	695.25	136	5
NTA Ile-Ife, Channel 39	615.25	136	5
NDTV Ibokun, Channel 22	479.25	150	3
OSBCTV Osogbo, Channel 32	559.25	150	30
REALITY TV Iwo, Channel 66	831.25	150	1
AIT TV Osogbo, Channel 26	511.12	150	5

With the introduction of new technologies in wireless networks, which have led to a spectrum shortage, the need for bandwidth has risen recently. A method for improving spectral efficiency proposed: in this research, using the free ultrahigh frequency (UHF) television (TV) channels, commonly known as TV white space (TVWS). Knowing the estimated amount of TVWS that is available is necessary for TVWS deployment. The Federal Communication Commission (FCC) rule was implemented as the protection viewpoint approach and the pollution viewpoint method to compute a quantitative estimation of the available TVWS in Southwest, Nigeria. According to the estimation's findings, the pollution viewpoint strategy will ensure sufficient defense from primary users and prevent interference from secondary users [11].

The research deduced that plenty of TVWS in the states was considered for deploying TVWS devices. With the ArcGIS application software, TVWS was calculated for Southwest, Nigeria, utilizing the protection viewpoint approach, the pollution viewpoint approach, and the FCC rule. The results were then presented on the administrative maps of each state. The number of unwatched channels in each state was also considered while estimating TVWS. Findings from the research demonstrate that adopting a pollution viewpoint for TVWS estimation will ensure adequate protection for primary users and prevent interference for secondary users. It was previously assumed that all occupied channels in each state are received in every part of the state. Southwest Nigeria is home to a large number of TVWS, with Ekiti State having 97.96% of them, Lagos State having 81.63%, Ondo State having 95.92%, Ogun State having 97.96%, Osun State having 95.92%, and Oyo State having 95.92%. Therefore, it was advised that the pollution viewpoint be used when deploying TVWS in Nigeria. The research's findings would be helpful to the Nigeria Communication Commission (NCC) in formulating policies for deploying and using TVWS in Nigeria [11].

In the review work of [12] on the management of interference for the coexistence of Long Term (LTE) and Digital Terrestrial Television (DTTV) systems in Nigeria, a digital dividend band was proposed. The investigation was focused on the interference between the fixed outdoor reception antenna for DTTV in Port Harcourt, Nigeria, and the LTE Downlink (DL) signal from the closest cell site. Since DTTV systems can only begin to function in the newly established frequency band with an assessment of the potential negative effects of the coexisting systems, qualitative signal analysis of the DTTV systems is crucial.

The researcher in [12] looked into how well the two systems work together and the likelihood that Channels 17 (490 MHz) and 51 (693 MHz) may interfere when DTTV and LTE systems coexist in the proposed Digital Dividend band. The necessary simulation data was generated using a testbed approach methodology. Victim Link Transmitter (VLT) and Interfering Link Transmitter (ILT) designations were given to Port Harcourt's Star Time Transmitting Station and Smile LTE 4G Communication LTE Base Station (eNBs) Network, respectively. Data was gathered, examined, and judged. The simulation's output revealed that the likelihood of interference depends on the separation between the ILT and VLR. The outcome of the research's compatibility indicates a low interference rate because the resulting Carrier-to-interference ratio (C/I) is above the protection threshold (19 dB). When the two systems coexist in the 700 MHz range, the interference problem may be addressed. It was also determined that DTTV channel 51 experiences higher interference for the same separation distance than DTTV channel 17. Since DTTV and LTE systems coexist in Nigeria's proposed digital dividend (700MHz) band, the study advocated the minimum protection distance approach (Interference Avoidance method) as the interference control strategy. After the signal leaves the transmitter, the DTTV Modulation Error Rate (MER) analysis reveals that Channel 17 has a lower MER than Channel 51. The study's findings on the interoperability of DTTV and LTE systems demonstrate that both may survive in Nigeria's proposed digital dividend band. The simulation's findings revealed that, for a certain separation distance between Smile 4G LTE base stations (ILT) and Star time Television Receivers (VLR), the chance of interference is a function of that distance, with DTTV channel 51 experiencing more interference than DTTV channel 17 does. In [12], the researcher was able to determine that at a separation distance of 0.5 km between the DTTV receiver and the LTE base station, the minimum permitted protection distance for channels 17 and channel 51 are, respectively, 0.31 km and 0.44 km at a distance from the transmitter of 0.5 km [12].

Investigations in [12] were conducted into the possibility of Long-Term Evolution (LTE) systems operating in a channel next to Digital Television (DTV) in the 700 MHz range. Many nations use these technologies to offer high-capacity broadband connections and terrestrial television broadcasts. Yet, there may be a direct influence on their ability to coexist in the 700 MHz range due to system interference. Through this effort, it was proposed to offer a thorough analysis of how DTV interference affects the functioning of the LTE system. The minimum separation distance was calculated to ensure that the LTE system can function without being interfered with by the DTV system. The effect of interference from several classes of DTV (Special, A, B, and C) on the LTE system was evaluated using Monte Carlo simulation. The findings indicate that Special-class DTV interference may limit the LTE channel capacity. On the other side, the findings indicate that the separation distances between the DTV tower and LTE base stations are respected. The LTE capacity loss caused by DTV interference may be significantly decreased by a group of models that use the Monte Carlo method to simulate the interference between LTE and Digital Television (DTV) in the 700 MHz band.

The simultaneous analysis of the interference caused by several DTV classes on LTE operating at various bandwidths. The findings demonstrate that DTV interference in the 700 MHz bands can impact LTE performance. The effects of this interference could lead to LTE system transmission errors and channel capacity reductions. Yet, since the proper separation distances and bandwidths are observed, this LTE capacity loss may be decreased by more than 90%, demonstrating that the LTE system can function with respectable performance levels. Due to the significant channel capacity losses and transmission errors that the interference from Special class generates on LTE, Special class DTV has proven impractical for deployment in channels next to the LTE system. On the other hand, once the interference from DTV classes B and C is minimized and the LTE capacity loss is below the threshold or null, the DTV of classes B and C can be put in the adjacent channel to the LTE system. If Classes B and C are accepted, LTE and DTV systems can coexist regardless of the separation distance [13].

It was investigated in [14] how the LTE (Long Term Evolution) and the DTTB (Digital Terrestrial Television Broadcasting) channels could coexist. Co-channel, higher and lower nearby channels are the three possibilities. For the investigation, a broadcast signal from channel 3 called ThaiPBS was used, representing the real-world situation in Thailand, where the DVB-T2 standard for digital terrestrial television broadcasting uses an 8 MHz bandwidth, and LTE's 5 MHz bandwidth is seen as an interference. A dynamic interference suppression method was devised to maximize the use of TV white space and reduce interference. The solution uses the protection ratio principle to reduce LTE interference on TV receivers. Using a Radio Frequency (RF) attenuator and a Raspberry Pi board as our testbed hardware, the suggested technique was implemented as an adaptive interference controller. The usefulness of the suggested algorithm was demonstrated by conducting tests on the testbed and using the Quality of Experience (QoE) assessment to judge the received TV signal's quality. A Log Periodic antenna is utilized in the testbed hardware to receive the DTTB signal. An RF digital transmitter and an ultra-high frequency (UHF) mixer are then used to combine the two signals. Finally, a field strength meter monitors the video picture quality and analyses the spectrum.

The investigation in [14] also shows that the suggested strategy can boost spectrum consumption by 100% while reducing perceived visual distortion by at least 62.5% for co-channel and 87.5% for adjacent channels. The essential idea behind TVWS (TV White Space) and its optimization through dynamic interference is also researched in [14]. This technique takes advantage of the protection ratio notion to shield a DTTB receiver from 5MHz LTE signals when the co-channel or adjacent channel is in operation. The algorithm's implementation using a Raspberry Pi as a testbed concluded that the co-channel and adjacent channel's proper D/U ratios are 15.93 dB and 10.67

dB, respectively. As a result, for co-channel and adjacent channels, respectively, this can reduce the perceived visual distortion by at least 62.5% and 87.5%. Moreover, this approach can boost any WSD's available frequency channel for co-channel, upper, and lower channels by 100%. Thus, the WSD can now function on the co-channel, adjacent channel, and the White Space channel, which it can only currently work on under normal circumstances. The proportion of video degradation is still considerable in actual utilization, even though this technology can reduce interference and boost spectrum consumption. Based on the success of the research in [14], it is strongly advised to implement automatic real-time interference control that considers digital television users' quality of experience. For instance, the TV receiver should include a device for notifying system management of interference. The signal generator's 5 MHz LTE signal is the only one considered. Unfortunately, the actual LTE parameters, including traffic volume and the geographic setting, have not been considered.

In [15], the current wireless communication environment is driving a paradigm change away from the traditional fixed spectrum assignment policy and toward intelligent and dynamic spectrum access due to the growth of bandwidth-driven applications. To offer low-cost and dependable wireless access, practical demands for effective spectrum usage have continued to drive the development of TV white space technologies. The switch from analogue to digital terrestrial television (DTT) is expected to increase the amount of spectrum available for TV white space access, and regulatory bodies in several nations have already started to investigate this possibility to alleviate spectrum constraints. The research in [15] thoroughly evaluates the modern approaches to TV white space technology and the actual deployments of pilot projects in Africa to portray the evolutionary patterns in the development of TV white space technology. The TV white space technology initiatives were presented, including rules and standards, commercial trials, research obstacles, unresolved problems, and future research objectives.

It also gives a brief account of the commercial developments in TV white space technology, illustrating the role of cognitive radio as an enabling technology for this field. It has been demonstrated that TVWS technology provides a dependable and reasonably priced wireless communications resource that can alleviate the current wireless system technology spectrum shortage. With the right technology, underserved populations in Africa's remote rural and urban areas could benefit economically from introducing wireless communications services. It was shown that there are enormous opportunities for utilizing TVWS technology to offer dependable and reasonably priced wireless communication services in Africa, where the unutilized TV broadcasting spectrum is abundant. TVWS technology is developing from a purely theoretical approach to a realistic implementation, as proven by a few TVWS trials implemented in several African nations, according to an analysis of current industry trends in wireless communications. Extensive work is being done to commercialize and standardize TV white space devices.

2. EQUATIONS ANALYSIS OF SYSTEM MODEL, PROPAGATION PARAMETERS

2.1 DAVIDSON Path-Loss Model

The Davidson model is a variant of the Hata model that operates between 150 MHz and 1500 MHz. The model has a transmission range of 20 km and has been routinely used to forecast analogue TV signals [9]. The fluctuation of error spread concerning distance for a 60 km route was plotted to examine the performance of the Davidson and Hata models. Up to roughly 30 km, Hata and Davidson's prediction models are symmetrical, although there is a tiny divergence between 24 km and 30 km, after which the Hata model underestimates route loss. Six correction factors are included in the Davidson model, bringing the range up to 300 km [16].

The Davidson path loss model's L_D is:

$$L_D = L_{HATA} + K_{Davidson} \quad (1)$$

$$K_{Davidson} = A(h_{te}, d_{km}) - S_1(d_{km}) - S_2(h_{te}, d_{km}) - S_3(f_c) - S_4(f_c, d_{km}) \quad (2)$$

L_D is the Davidson path loss model in db.

$$L_{HATA} = 69.55 + 26.1 \times \log_{10}(f_c) - 13.82 \times \log_{10}(h_e) - a(h_{re}) + (44. - 6.5 \times \log_{10}(h_{te}))\log_{10}(d) \quad (3)$$

$$a(h_{te}) = \begin{cases} (1.1log_{10}(f_c) - 0.7) \times h_{re} - (1.56 \times log_{10}(f_c) - 0.8); for\ medium\ small\ city \\ 8.29\left(log_{10}(1.54 \times h_{re})\right)^2 - 1.1; for\ large\ city\ and\ f_c \leq 300\ MHz \\ 3.2\left(log_{10}(11.75 \times h_{re})\right)^2 - 4.97; for\ large\ city\ and\ f_c > 300\ MHz \end{cases} \quad (4)$$

$$A(h_{te}, d_{km}) = \begin{cases} 0; & d_{km} < 20\ km \\ 0.62317 \times (d_{km} - 20)[0.5 + log_{10}(h_{te}/121.92)]; & 20km \leq d_{km} < 64.38km \\ 0.62317 \times (d_{km} - 20)[0.5 + log_{10}(h_{te}/121.92)]; & 64.38\ km \leq d_{km} < 300\ km \end{cases} \quad (5)$$

$$S_1(d_{km}) = \begin{cases} 0; & d_{km} < 20\ km \\ 0; & 20km \leq d_{km} < 64.38\ km \\ 0.174(d_{km} - 64.38); & 64.38\ km \leq d_{km} < 300\ km \end{cases} \quad (6)$$

$$S_2(h_{te}, d_{km}) = 0.00784 \times \left| log_{10}\left\{\frac{9.98}{d_{km}}\right\}\right| \times (h_{te} - 300); for\ h_{te} > 300km \quad (7)$$

$$S_3(f_c) = \frac{f_c}{250 \times log_{10}\left(\frac{1500}{f_c}\right)} \quad (8)$$

$$S_4(f_c, d_{km}) = \left[0.112 \times log_{10}\left(\frac{1500}{f_c}\right)\right](d_{km} - 64.38); for\ d_{km} > 64.38\ km \quad (9)$$

Table 2. Summary of variables in Hata pathloss and Davidson derivation [24]

Variable	Definition
L_D	Hata-Davidson path loss (dB)
L_{HATA}	Hata pathloss (dB)
$K_{Davidson}$	Davidson correction factor (dB)
$L_{D(u)}$	Hata pathloss in urban area (dB)
$L_{D(S)}$	Hata pathloss in Suburban area (dB)
$L_{D(R)}$	Hata pathloss in rural area (dB)
d_{km}	Distance between transmitter and receiver (km)
f_c	Transmitter centre frequency ,$150 \leq f_c \leq 1000$ (MHz)
h_{te}	Transmitter antenna height (m)
h_{re}	Receiver antenna height (m)
$A(h_{te}, d_{km})$	Distance correction factor
$S_1(d_{km})$	Distance correction factor
$S_2(h_{te}, d_{km})$	Base station antenna height correction factor
$S_3(f_c)$	Frequency functions of f_c
$S_4(f_c, d_{km})$	Frequency functions of f_c

2.2 Signal Field Strength Evaluation

Signal field intensity can be estimated using the magnitudes of path-loss estimation at various distances from the transmitter. For WSDs to assess the affected range, the protection range of the Digital TV (DTV) service was computed based on the digital television sensing level. For this, a DTV relay with a 10 W output power was considered, and the signal strength was determined using ITU-R P.1546 based on the distance between the TV transmitter and the relay [17]. The digital TV signal ratio advised by ATSC, i.e., the D/U ratio, was utilized to establish the effective signal range of the DTV service, depending on the frequency employed [18].

In addition, 41 dBμV/m was used as the reference for DTV coverage in Korea [15]. The signal power unit was converted from the electric field strength unit (dBμV) for computational ease in equation (10) [3].

$$P_t(dBm) = E(dB\mu) - 130.8 + 20 \times log_{10}\left(\frac{615}{f_{mid}}\right) \quad (10)$$

when P_t indicates the field strength power in dBm, E is the signal field strength in dBμ, f_{mid} indicates the median frequency in MHz.

2.3 Signal-to-Noise Ratio (SNR) Evaluation

The signal-to-noise ratio (SNR) was evaluated by [22], here it is given by equation (11) as

$$SNR = P_t + G_t + G_r - L_D - L - N - IM \geq 16dB \quad (11)$$

where SNR is (in dB), G_t is the antenna gain of the transmitter (in dB), G_r is the antenna gain of the receiver (in dB), L_D is the Davidson path loss (in dB) L is the margin additional loss = 10 dB, N is the heat noise = - 105.2 dB, IM is the interference margin = 3 dB.

3. METHODOLOGY

The critical systems in this study were television channels 32 (OSBC TV Osogbo) and 49 (NTA Osogbo) in Osogbo, Osun State, Southwest, Nigeria. Many TV channels in the TVWS, on the other hand, were recognized as subsidiary systems. The Grade B contour is examined when a transmitter connects with primary receivers within a noise-limited zone [21]. If the frequency is relatively close to the Primary User's (PU) cell border, the Secondary User (SU) can reuse it if it meets the FCC white space requirements. When the received signal strength for channels 7 through 13 and channels 14 through 69 for UHF DTV systems exceeding 41 dB, the television service coverage region is defined as the area within the Television noise-limited grade B contour [21].

To ensure that the Primary User (PU) is well-protected, the Secondary Users (SUs) must be located outside the grade B contour of the incumbent user, in line with the FCC's minimum protection distance being strictly followed [12].

To ensure that the primary and secondary systems coexist, the threshold of 16 dB SNR for the noise-limited region must be met. The concept of spatial and temporal for white space device (WSD) needs to be considered, where temporal is the operation of the TV transmitter in downtime mode and spatial is the operation of the TV transmitter outside the coverage area.

2.4 Analysis of Total Interference

By adding the weighted sum of the interferences from different channels [20], the total effect of various channel interferences can be determined, which converges at point P, in Figure 1. Assuming that the SU on channel y transmits at Ps, the interference seen by a TV on channel x in pixel I is:

$$I_S = P_S + G_r - g - L_D \quad (12)$$

where g is the channel fading random variable in decibels, Gr is the TV receiver antenna gain in decibels, and L_D is the SU-TV receiver path loss in decibels. As a result, the total interfering strength from each secondary transmitter is:

$$I_{total} = \sum_{i=1}^{N} Ii = \sum_{i=1}^{N} \frac{S}{N} P_S + g + G_r + L_D \quad (13)$$

The deployment of various secondary networks outside of the TV protection region is depicted in Figure 1. Figure 2 shows spectrum sharing for a single primary transmitter and a single secondary user, with rp representing the protection contour radius, rn representing the no-talk radius, and dn(Δ) representing the protection region. As a result, no conversation width is written in the following format [21]:

$$r_n = r_p + d_n(\Delta) \quad (14)$$

UHF TV signal service coverage was tested at 41 dBu. All channels had their signal-to-noise ratios analyzed, with channels 33 and 43 being chosen for dual network deployment and the others serving as backup channels. If primary TV systems license users are discovered on channels 33 and 43, secondary networks can use any backup channels. The separation distance was computed using the noise-limited zone, defined as an area with a signal-to-noise ratio greater than 16 dB.

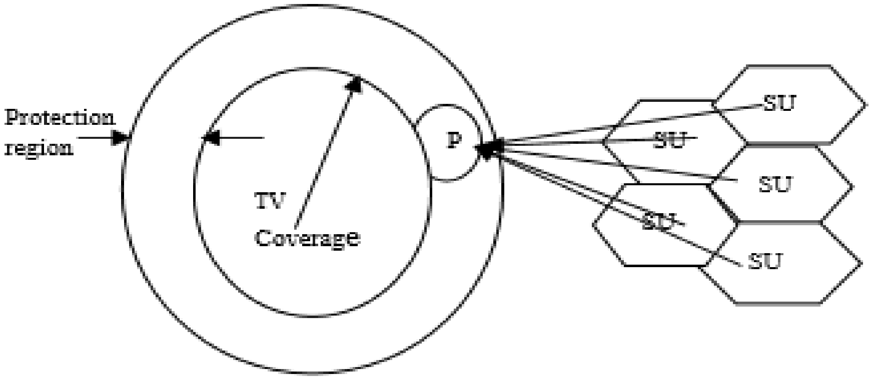

Figure 1. Multiple Network deployment for secondary use outside TV protection area [21]

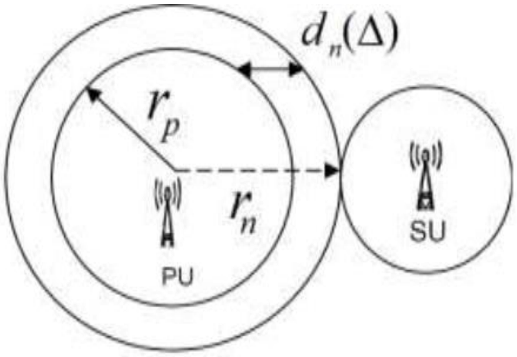

Figure 2. Spectrum Sharing for Single Secondary User [21].

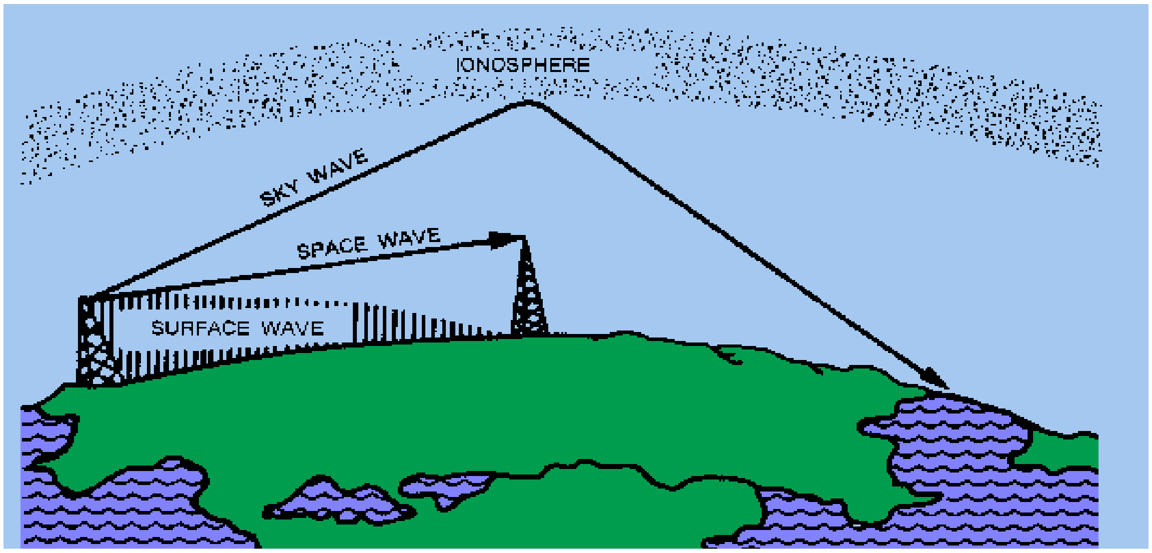

Figure 3. Propagation Path of Radio Waves for Terrestrial Transmission [22]

Table 3a. System Parameters from Television Stations in Osun State

Parameters	Values
Channels	32 (OSBC), 49 (NTA OSOSGBO)
Frequency	559.25, 695.25
Power of Transmission (KW)	1, 2, 2.5, 5, 10 &100
Height of Receiver Above Terrain (m)	10
Protection margin of FCC limit (dBm)	-114
Noise limited contour D/U ratio (dBm)	15.5

Table 3b. Emergency Communication Network System Parameters

Parameters	Values
Channels	23, 33, 43, 53 and 63
Frequency	486, 566, 646, 726 and 806
Power of Transmission (W)	0.04, 0.1, 0.25, 0.5, 1, 2, 4
Antenna Height of BS (m)	10,30,50, 100, 150, 200
Antenna Height of Receiver (m)	1.5
Antenna Gain of Transmitter (dBi)	16
Antenna Gain of Receiver (dBi)	8
Protection margin of FCC limit (dBm)	-114
Noise limited contour D/U ratio (dBm	15.5

4. RESULT ANALYSIS

4.1 Results of Adjacent Channel Scenarios

In the analysis and graphical representation, Television White Space, Signal Noise Ratio and Signal Strength were abbreviated as TVWS, SNR and SSTR, respectively. Figures 4 and 5 demonstrate the results of adjacent channels for spatial TVWS for 5 kW EIRP for the primary transmitter and 4 Effective Isotropic Radiated Power (EIRP) for the secondary transmitter, signal field strength and SNR are plotted versus distance. The coverage distance for channels 32 and 49 is calculated to be 44 km and 48 km, respectively, if a power of 5 kW is transmitted in channels 32 and 49 with an antenna height of 150 m.

When the transmitter power for the two secondary systems is 4 W (maximum EIRP) and the antenna height is 30 m (maximum antenna height above ground), the coverage distances for channels 33 and 43 are 1.3 km and 1.28 km, respectively, as presented in Figure 4 and summarized in Table 4. Channels 32 and 33 have noise-limited service coverage distances of 13.3 km and 0.37 km, respectively, as presented in Figure 5 (with an SNR threshold of 16 dB). The TV receiving antenna and the ECN-BS antenna are separated by 0.93 km. Channels 49 and 43 have noise-limited service coverage distances of 11 and 0.34 kilometers, the TV receiving antenna and the hybridization of the Emergency Communication Network (ECN) and that of the Base Station (BS) antenna, known as the ECN-BS antenna, are separated by 0.94 km.

Figures 6 and 7 present the results of nearby channels for spatial TVWS for a 5 kW EIRP primary transmitter and a 40 mW EIRP secondary transmitter when signal field strength and SNR are plotted versus distance. The coverage distances for channels 32 and 49 are 44 km and 48 km, respectively, when 5kW is transmitted with a 150 m antenna height. When the transmitter power for the two secondary systems is 40 mW (maximum) and the antenna height is 30 m (maximum antenna height above ground), the coverage areas for channels 33 and 43 are 0.35 km and 0.34 km, respectively, as shown in Figure 6.

In the adjacent channel scenarios shown in Figure 7, the noise-limited service coverage distances for channels 32 and 33 (obtained at SNR=16 dB) are 1.33 km and 0.1 km, respectively. In contrast, the separation distance between the TV receiver antenna and the ECN-BS antenna is 0.25 km. Channels 49 and 43 have noise-limited service coverage distances of 11 km and 0.09 km, respectively, whereas the distance between the TV receiver and the ECN-BS antenna is 0.25 km. The summaries can be found in Tables 6 and 7.

Table 4. Summary for Channel 32 and 33 Adjacent Scenario at 4W Secondary Transmitter

Channel	Channel type	Frequency (MHz)	EIRP Transmitting Power in Watt	Coverage distance (km) at 41 dBu SSTR	Noise-limited service coverage distance (km) at 16 dB SNR	Separation distance (km) between SSTR and SNR value
32	Primary	559.25	5000	44	13.3	30.7
33	Secondary	566	4	1.3	0.37	0.93

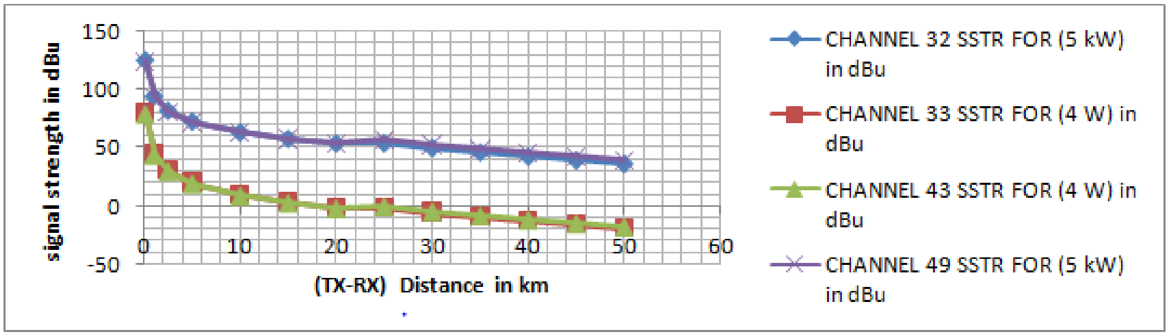

Figure 4. Signal field strength for primary (150 m antenna height) and secondary (30 m antenna height and EIRP of 4W) system in adjacent scenario

Table 5. Summary for Channel 49 and 43 Adjacent Scenario at 4W Secondary Transmitter

Channel	Channel type	Frequency (MHz)	EIRP Transmitting Power (Watt)	Coverage distance (km) at 41 dBu SSTR	Noise-limited service coverage distance (km) at 16 dB SNR	Separation distance (km) between SSTR and SNR value
49	Primary	695.25	5000	48	11	37
43	Secondary	646	4	1.28	0.34	0.94

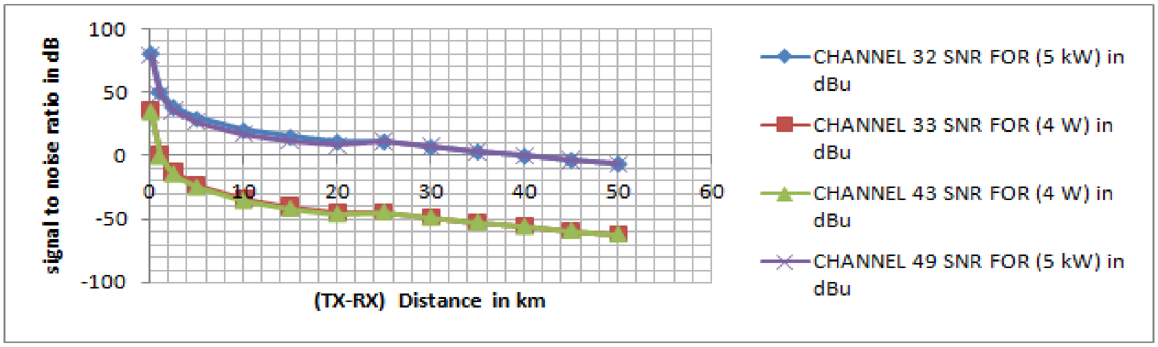

Figure 5. SNR for primary (150 m antenna height) and secondary (30 m antenna height and EIRP of 4W) system in adjacent scenario

Table 6. Summary for channel 32 and 33 adjacent scenarios at 40 mW secondary transmitter

Channel	Channel type	Frequency (MHz)	EIRP Transmitting Power (Watt)	Coverage distance (km) at 41 dBu SSTR	Noise-limited service coverage distance (km) at 16 dB SNR	Separation distance (km) between SSTR and SNR value
32	Primary	559.25	5000	44	13.3	30.7
33	Secondary	566	0.04	0.35	0.1	0.25

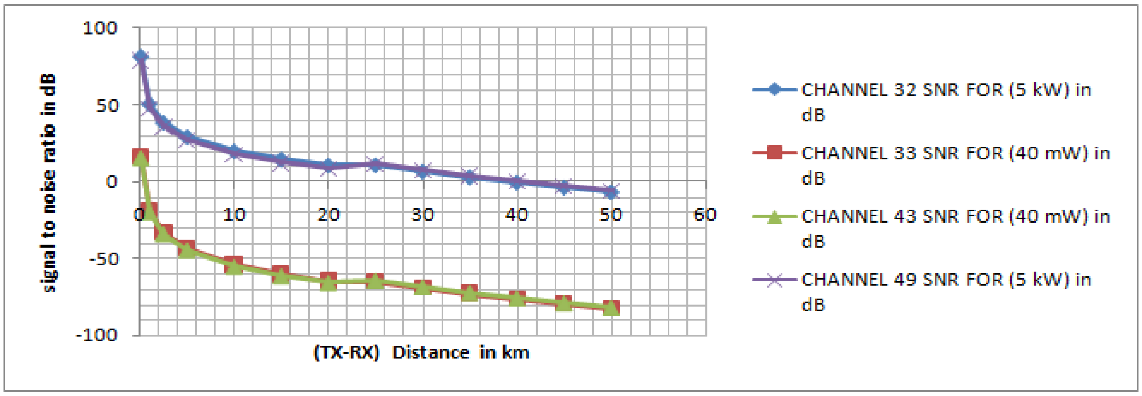

Figure 6. Signal field strength for primary (150 m antenna height) and secondary (30 m antenna height and EIRP of 40 mW) systems in adjacent scenarios

Table 7. Summary for channel 49 and 43 adjacent secondary transmitter scenario at 40 mW

Channel	Channel type	Frequency (MHz)	EIRP Transmitting Power (Watt)	Coverage distance (km) at 41 dBu SSTR	Noise-limited service coverage distance (km) at 16 dB SNR	Separation distance (km) between SSTR and SNR value
49	Primary	695.25	5000	48	11	37
43	Sec.	646	0.04	0.34	0.09	0.25

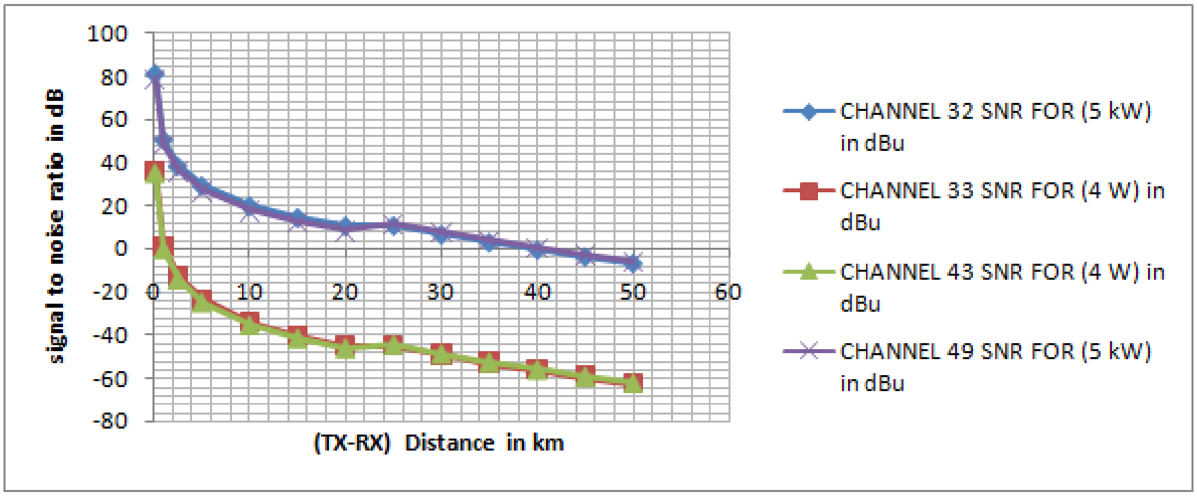

Figure 7. SNR for Primary (150 m antenna height) and secondary (30 m antenna height and EIRP of 40 mW) System in adjacent scenario

4.2 Results of Co-Channel Scenarios

When ECN-BS are transmitting through channels 32 and 49 at 4 W (EIRP) in co-channel systems with a 30 m antenna height, as shown in Figure 8 and summarized in Table 8, the results are as follows: Channel 32 offers noise-limited service coverage distances of 13.3 km and 0.38 km (with 5 kW and 4 W transmitter outputs).

On the other hand, the separation distance between the TV receiver antenna and the ECN-BS antenna is 0.9 km. Noise-limited service coverage distances for channels 49 are 11 km and 0.32 km, respectively, as shown in Figure 9 and Table 9. The TV receiving antenna and the ECN-BS antenna are separated by 0.96 km.

Channels 32 and 49 have coverage distances of 44 km and 0.36 km, respectively, when utilizing a mobile device with a maximum EIRP of 40 mW, as illustrated in Figure 10 and summarized in Table 10. Noise-limited service coverage distances of 13.3 km and 0.1 km are available on Channel 32 (with 5 kW and 40 mW transmitter outputs).

On the other hand, the distance between the TV receiver antenna and the ECN-BS antenna is 0.26 km. The noise-limited service coverage distances for channels 49 are 11 km and 0.09 km, respectively, as shown in Figure 11 and summarized in Table 11. The TV receiving antenna and the ECN-BS antenna are separated by 0.26 km.

Table 8. Summary for channel 32 (primary) and 32 (secondary) co-channel scenario at 4 W

Channel	Channel type	Frequency (MHz)	EIRP Transmitting Power (Watt)	Coverage distance (km) at 41 dBu SSTR	Noise-limited service coverage distance (km) at 16 dB SNR	Separation distance (km) between SSTR and SNR value
32	Primary	559.25	5000	44	13.3	30.7
32	Sec.	559.25	4	1.28	0.38	0.9

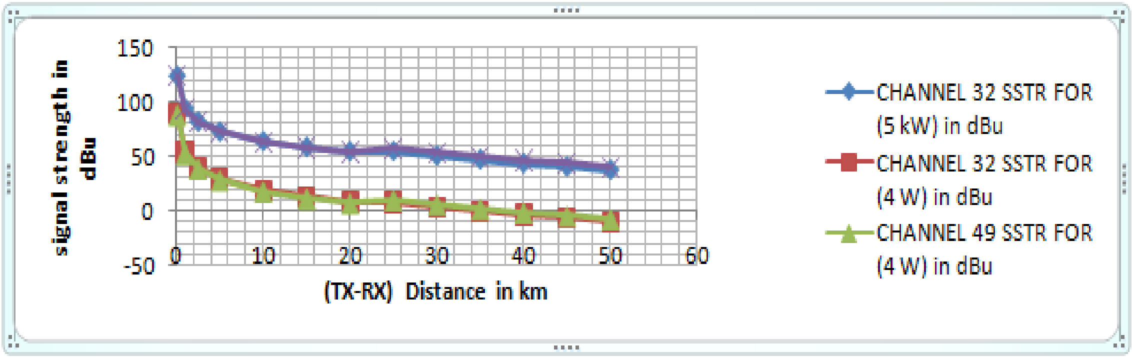

Figure 8. Signal field strength for primary (with 150 m transmitting antenna and 10 m receiving antenna) and secondary (with 30 m transmitting antenna and 10 m receiving antenna) systems in co-channel scenario at 4 W

Table 9. Summary for channel 49 (primary) and 49 (secondary) co-channel scenario at 4 W

Channel	Channel type	Frequency (MHz)	EIRP Transmitting Power (Watt)	Coverage distance (km) at 41 dBu SSTR	Noise-limited service coverage distance (km) at 16 dB SNR	Separation distance (km) between SSTR and SNR value
49	Primary	695.25	5000	48	11	37
49	Sec.	695.25	4	1.25	0.32	0.96

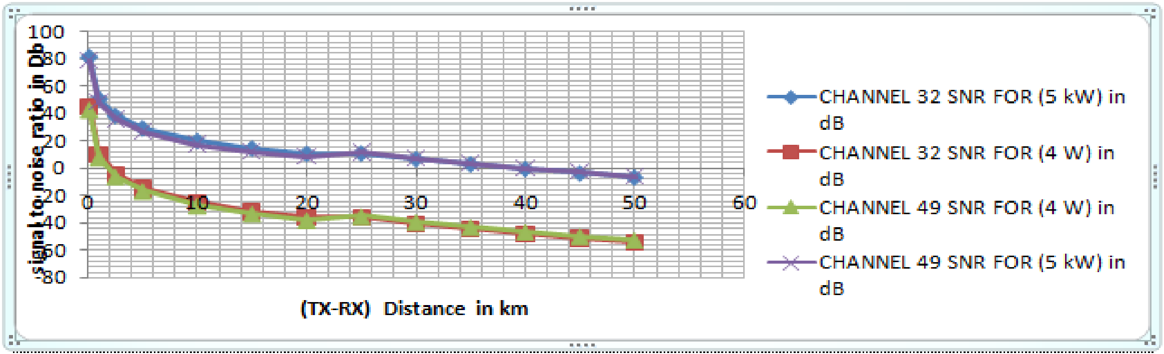

Figure 9. SNR for primary (with 150 m transmitting antenna and 10 m receiving antenna) and secondary (with 30 m transmitting antenna and 10 m receiving antenna) systems in co-channel scenarios at 4 W

Table 10. Summary for channel 32 (primary) and 32 (secondary) co-channel scenario at 40 mW

Channel	Channel type	Frequency (MHz)	EIRP Transmitting Power (Watt)	Coverage distance (km) at 41 dBu SSTR	Noise-limited service coverage distance (km) at 16 dB SNR	Separation distance (km) between SSTR and SNR value
32	Primary	559.25	5000	44	13.3	30.7
32	Sec.	559.25	0.04	0.36	0.1	0.26

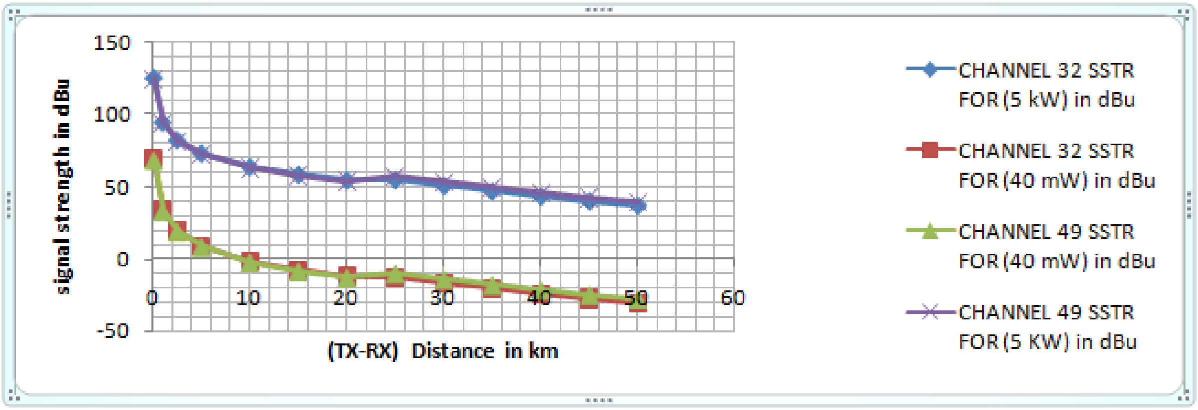

Figure 10. Signal field strength for primary (with 150 m transmitting antenna and 10 m receiving antenna) and secondary (with 30 m transmitting antenna and 10 m receiving antenna) systems in co-channel scenarios at 40 mW

Table 11. Summary for channel 49 (primary) and 49 (secondary) co-channel scenario at 40 mW

Channel	Channel type	Frequency (MHz)		EIRP Transmitting Power (Watt)	Coverage distance (km) at 41 dBu SSTR	Noise-limited service coverage distance (km) at 16 dB SNR	Separation distance (km) between SSTR and SNR value
49	Primary	695.25		5000	48	11	37
49	Sec.	695.25		0.04	0.35	0.09	0.26

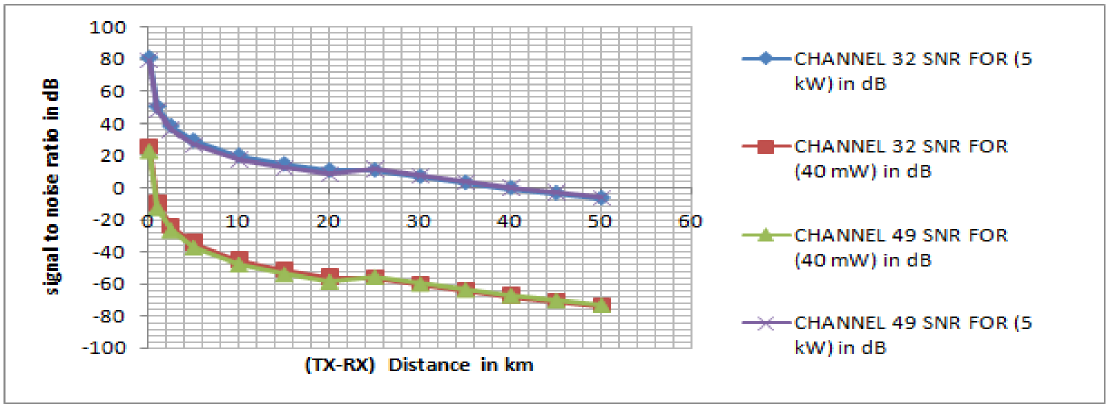

Figure 11. SNR for primary (with 150 m transmitting antenna and 10 m receiving antenna) and secondary (with 30 m transmitting antenna and 10m receiving antenna) systems in co-channel scenarios at 40 mW

5. CONCLUSION

In this work, the effects of adjacent and co-channel scenarios on the TVWS device, and the coverage area for the associated primary and secondary channels, were explored using EIRPs of 4 W and 40 mW and an antenna height of 30 m. At a signal strength threshold of 41 dB, the separation distance between the TV receiving antenna and the base station antenna for the ECN network device was also measured. The noise-limited service coverage distances were also discovered at an SNR threshold of 16 dB.

When used spatially in TVWS, the secondary device will have no adverse effect on the primary device. It will be a significant benefit in preserving our primary transmitters for the primary mission they were designed for in the telecommunications and broadcasting industries, according to the analysis of the table and graph.

Changing the transmitting power and antenna height on the TV system's service coverage region revealed the effect of interference scenarios in terms of adjacent and co-channel channels for the two primary (channels 32 and 49) and secondary (channels 33 and 43) channels, as well as the backup channels 23, 53, and 63. The TV system's coverage area and the minimum separation distance between the TV receiver's antenna and the ECN's base station were computed. The coverage reduction ratio is also investigated when the ECN runs at acceptable isotropic radiated power levels. The results of this study confirm the effects of the TV-ECN interference scenario in that effective parameter selection is made for both fixed and mobile devices to avoid harmful interference to incumbent TV users, especially for UHF, where extra white space will be available when the FCC's minimum threshold of -114 dBm is taken into account. Additional sensing margins of 3.76dB and 4.04dB must be added to the -114 dBm stipulated by FCC requirements for the TV white region to not interfere with the consumers' network to deploy the Emergency Communication Network.

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