Quantitative Assessment of TV White Space in India

Gaurang Naik, Sudesh Singhal, Animesh Kumar, and Abhay Karandikar
Department of Electrical Engineering
Indian Institute of Technology Bombay
Mumbai - 400076
Email: {gaurangnaik,sudesh,animesh,karandi}@ee.iitb.ac.in

***Abstract*—Licensed but unutilized television (TV) band spectrum is called as TV white space in the literature. Ultra high frequency (UHF) TV band spectrum has very good wireless radio propagation characteristics. The amount of TV white space in the UHF TV band in India is of interest. Comprehensive quantitative assessment and estimates for the TV white space in the 470-590MHz band in India is presented in this work. This is the first effort in India to estimate TV white spaces in a comprehensive manner. The average available TV white space per unit area in India is calculated using two methods: (i) the primary (licensed) user and secondary (unlicensed) user point of views; and, (ii) the regulations of Federal Communications Commission in the United States. By both methods, the average available TV white space in the UHF TV band is shown to be more than 100MHz! A TV transmitter frequency reassignment algorithm is also described. Based on spatial-reuse ideas, a TV channel frequency allocation scheme is presented which results in insignicant interference to the TV receivers while using the smallest bandwidth for existing transmission across India. In the proposed reassignment, it is found that eight TV band channels (or 64MHz) are sufficient to provide the existing UHF TV band coverage in India.**

***Index Terms*—TV broadcasting, radio spectrum management, interference**

I. INTRODUCTION

With rising demand for bandwidth, the occupancy of spectrum has been measured in different countries. These measurements suggest that except for the spectrum allocated to services like cellular technologies, and the industrial, scientific and medical (ISM) bands, most of the allocated spectrum is heavily underutilized. The overall usage of the analyzed spectrum is quite low—4.54% in Singapore [1], 6.2% in Auckland [2], 17.4% in Chicago [3], and 22.57% in Barcelona [4]. In underutilized frequency spectrum, the Ultra High Frequency (UHF) Television (TV) bands have been of particular interest due to the superior radio-propagation characteristics as compared to the higher frequency bands.

Informally, the unutilized (or underutilized) TV channels collectively form the TV white spaces. The amount of available TV white space varies with location and time. TV white space estimation has been done in countries like the United States (US), the United Kingdom (UK), Europe, and Japan [5], [6], [7], [8]. In the Indian context, single-day experiments at three locations in urban and sub-urban Delhi have been performed [9]. A preliminary investigation of TV white spaces in South India has been done as well [10]. In this work, a comprehensive estimation of TV white space in the UHF band, based on spectrum allocation and TV transmitter parameters, is presented. Our main contributions are as follows:

1) For the first time, the empirical quantification of the available TV white space in the 470-590MHz in India is presented. The quantification utilizes existing methods, namely pollution and protection viewpoints [5], and the technical specifications of the Federal Communications Commission (FCC) [11]. It is found that UHF TV band spectrum is heavily underutilized in India.
2) Indian UHF TV band spectrum is underutilized; so, a TV transmitter frequency assignment algorithm has been proposed for the TV transmitters operating in 470-590MHz. The algorithm minimizes transmission bandwidth while ensuring negligible interference between TV receivers operating at the same frequency. We show that 40% UHF TV band channels can be freed in this way.

The importance of the above results must be understood in the context of Indian National Frequency Allocation Plan (NFAP) 2011 where a policy intent for the utilization of TV white spaces was made. Therefore, it is necessary to estimate TV white space in India. Our results show that the UHF TV band in India is underutilized; this is in contrast to the developed countries. The optimal methods for TV white space usage in India may be *unique* and should be studied by further research.

Organization: The TV white space scenario and related work on its quantitative analysis in a few countries is described in Sec. II. The current Indian usage scenario of the UHF TV Bands is described in Sec. III. The methodology and assumptions used in calculating the white space availability in India is explained in Sec. IV. The TV white space estimates for India and its comparison with TV white space in other countries is described in Sec. V. In Sec. VI, a frequency allocation scheme to the TV transmitters in India is proposed to minimum bandwidth used. Concluding remarks and directions for future work are discussed in Sec. VII.

II. TV WHITE SPACE IN OTHER COUNTRIES

The regulators, FCC in the US and Ofcom in the UK, have allowed for secondary operations in the TV white spaces. Under this provision, a secondary user can use the unutilized TV spectrum provided it does not cause harmful interference to the

TV band users and it relinquishes the spectrum when a primary user (such as TV Transmitter) starts operation. Since the availability of TV white spaces varies with location and time, secondary service operators are interested in the amount of available white space. The available TV white space depends on regulations such as the primary user protection margin, maximum height above average terrain (HAAT), secondary user power, and the separation distance.

As per FCC, a band can be declared as unutilized if no primary signal is detected above a threshold of -114dBm [11]. Using the parameters of terrestrial TV towers, TV white space availability in the US has been done in the literature [5]. The average number of channels available per user has been calculated using the pollution and protection viewpoints.[1] These viewpoints are explained in more detail in Sec. IV. Using the pollution viewpoint into account, the average number of channels available per location increases with the allowable pollution level. This average number of available channels is maximum in the lower UHF band. In the protection viewpoint too, the average number of available channels at a location is maximum in the lower UHF band (channels 14-51 of the US) and this decreases as more and more constraints are applied. In UK, Ofcom published a consultation providing details of cognitive access to TV white spaces in 2009 [12]. The coverage maps and database of digital TV (DTV) transmitters can be used to develop a method for identification of the TV white space at any location within UK [6]. The TV white space availability in Japan has also been studied in [8]. The results of [8] indicate that the amount of available TV white space in Japan is larger than that in US and UK. However, this availability decreases with an increase in the separation distance.

To the best of our knowledge, a comprehensive study of TV white space availability has not been done in India and is the focus of this work.

III. Current Indian TV Band Plan

As per the NFAP 2011 [13], the spectrum in the frequency band 470-890MHz is earmarked for Fixed, Mobile and Broadcasting Services. The NFAP has allowed the digital broadcasting services to operate in the 585-698MHz band. India is a part of the ITU Region 3, and the 698-806MHz band has been earmarked for International Mobile Telecommunications-Advanced (IMT-A) applications (see footnote IND 38 of [13]). Hence, the digital TV broadcasting will operate in the frequency band from 585MHz to 698MHz. Currently the TV transmitters operate only in the 470-590MHz band in the UHF band.

In India, the sole terrestrial TV service provider is Doordarshan which currently transmits in two channels in most parts across India. Currently Doordarshan has 1418 TV transmitters operating in India, out of which 8 transmitters transmit in the VHF Band-I (54-68MHz comprising of two channels of 7MHz each), 1034 transmitters operate in the VHF Band-III (174-230MHz comprising of eight channels of 7MHz each), and the remaining 376 transmitters transmit in the UHF Band-IV (470-590MHz comprising of fifteen channels of 8MHz each). In India, a small number of transmitters operate in the UHF bands. As a result, apart from 8-16MHz band depending on the location, *the UHF band is quite sparsely utilized in India*! This observation will be made more precise in the next section.

IV. Methodology

The quantification of TV white space in India will be addressed in this section. A computational tool has been developed that calculates the protection region and separation distance for each tower, and also the pollution region around the tower where a secondary device should not operate. Currently, there are no TV white space regulations in India. The regulations of FCC (US) are borrowed for the estimation of TV white space in India. *Microphones are ignored in our computation due to lack of available information*. The input to the developed computational tool include the following parameters for all the TV transmitters:

1) position of the tower (latitude and longitude),
2) transmission power of the TV transmitter,
3) frequency of operation,
4) height of the antenna,
5) and, terrain information of area surrounding the tower.

The above parameters of all the TV towers operating in the UHF band-IV have been obtained from the terrestrial TV broadcaster Doordarshan.[2] Doordarshan has provided data of 376 towers operating across India.

Comprehensive field strength measurements in India suggest that Hata model is fairly accurate for propagation modeling [15], [14]. The Hata model will be used for path-loss calculations. Using the TV transmitter information and the propagation model, we quantify the available TV white space in the UHF TV band by two methods. The first method utilizes the protection and pollution viewpoints while the second one utilizes technical specification made by the FCC.

A. Method 1: the protection and pollution viewpoints

The protection and pollution viewpoints used for calculating TV white space have been introduced by Mishra and Sahai [5]. Their method is reviewed in this section and utilized in our work for obtaining TV white space availability (see Sec. V).

1) Protection viewpoint: In the protection viewpoint, when a secondary user operates, it must not cause any interference to the primary receivers in its vicinity. This is illustrated in Fig. 1 The protected area is defined using the following SINR equations. Let P_t be the transmit power of primary in dBm, $PL(r)$ be the path-loss in dB at a radial distance r from the transmitter, N_0 be the thermal noise in dBm, and Δ be

[1] The pollution viewpoint looks at TV white space calculations from the secondary users' point of view, whereas the protection viewpoint is concerned with avoiding interference to the primary users [5].

[2] While the TV tower data is available online publicly in US and other countries, it is not so in India. We could obtain the data with considerable efforts from Doordarshan.

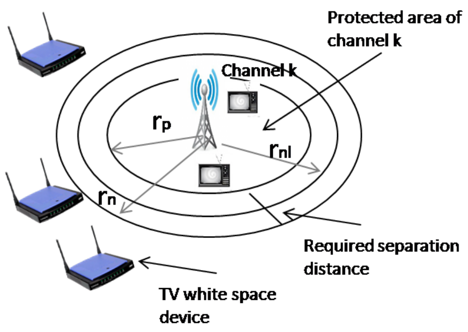

Fig. 1. Protection radius, separation distance and the no-talk radius

the threshold SINR in dBm. Then, the protection radius r_p is defined by the following SINR equation,

$$P_t - PL(r_p) - N_0 = \Delta.$$

The regulator provides an additional margin (Ψ) to account for fading. The modified equation for r_p is,

$$P_t - PL(r_p) - N_0 = \Delta + \Psi.$$

The no-talk radius r_n is defined as the distance from the transmitter up to which no secondary user can transmit. The difference $r_n - r_p$ is calculated such that if a secondary device transmits at a distance of $r_n - r_p$ from the TV band receiver located at r_p, the signal to interference plus noise ratio (SINR) at the TV band receiver within a radius r_n does not fall below Δ.[3] The separation distance $r_n - r_p$ is then calculated such that

$$P_s - PL(r_n - r_p) = \Psi,$$

where, P_s is the secondary transmitter power in dBm.

In addition to the co-channel considerations, a TV receiver tuned to a particular channel has a tolerance limit on the interference level in the adjacent bands. In the protection viewpoint, we consider that the protection radius in the adjacent channel is the same as in co-channel. However, the TV receiver can tolerate more adjacent channel interference than co-channel interference. Therefore, a margin of 27dB more than co-channel fading margin Ψ (set by the FCC regulations [11]) is provisioned for adjacent channel interference.

2) Pollution viewpoint: The pollution viewpoint takes into consideration the fact that even though a region could be used by a secondary device, the interference at the secondary receiver due to the primary transmitter might be higher than the tolerable interference level of the secondary receiver. If γ is the interference tolerable by the secondary receiver, then r_{pol} is given by,

$$P_t - PL(r_{\text{pol}}) = N_0 + \gamma.$$

Similar to the protection viewpoint, there are adjacent channel conditions (leakage of primary transmitter's power in the adjacent channel) in the pollution viewpoint as well. It is assumed that the secondary device can tolerate up to 45dB of interference if it is operating in the adjacent channels. The TV white space available is the *intersection* of the white space determined from the pollution and protection viewpoints.

[3]For simplicity, only one secondary device transmitting around the primary receiver is considered.

The parameters used in our computations for calculating the available TV white space are given in Table I. As an example,

TABLE I
PARAMETERS USED FOR CALCULATION OF TV WHITE SPACE USING POLLUTION AND PROTECTION VIEWPOINTS

Pollution Viewpoint	
Maximum tolerable interference (γ) by secondary	5dB 15dB (specified for 802.11g systems)
Maximum tolerable interference (γ) by secondary (adjacent channel)	45dB
Noise in a 8MHz band (N_0)	-104.97dBm
Protection Viewpoint	
Target fading margin (Ψ)	0.1dB 1dB (specified by FCC)
Additional fading margin in adjacent channel	27dB (specified by FCC)
Required SINR for primary receiver	45dB
Transmission power of secondary device	36dBm
HAAT of secondary device	30m

we consider the TV tower located at the Sinhagad Fort in Pune. The tower at Sinhagad Fort operates in the 534-542MHz band (channel 29) at a height of 100m and power of 10kW (70dBm). In the Hata model used for path loss calculations, Pune has been considered as an urban city. Using the pollution viewpoint, for a 15dB tolerable interference in channel 29 (534-542MHz), the pollution radius for the tower is calculated to be 37.70km, and for a tolerable interference of 45dB in the adjacent channel, the pollution radius is 4.24km. What this means for a secondary device is that the interference level is more than the allowable limit (15dB above noise floor) in a region of 37.70km in channel 29 and 4.24km in the adjacent channels around the tower.

From the protection viewpoint, if a fading margin of 1dB is provided, the protection and no-talk radius in channel 29 are 33.82km and 33.83km respectively. If we consider an additional fading margin of 27dB in the adjacent band, the no talk radius in the adjacent channel is 33.82km. This implies that if a secondary device operates within a distance of 33.83km in channel 29 and 33.82km in the adjacent channels, the primary user receiving on channel 29 will experience interference. The available white space is the intersection of the white space using the two viewpoints. Thus, in Pune, no secondary device can operate within a distance of 37.70km (limit set by pollution viewpoint) on channel 29 and 33.82 km in the adjacent channels (limit set by protection viewpoint) around the tower at Sinhagad Fort.

B. Method 2: TV white space calculation using FCC rules

In the FCC's definition of TV white space, the protection radius is same in the Grade B contour (r_b) [5], [11]. In the

UHF band, r_b is the distance from the TV tower where the field strength of the primary signal falls to 41dBu. The required field strength is converted from from dBu to dBm using the following conversion formula [16],

$$P(\text{dBm}) = E(\text{dBu}) - 130.8 + 20\log_{10}\left(\frac{1230}{f_H + f_L}\right),$$

where, $P(\text{dBm})$ is transmit power in dBm, $E(\text{dBu})$ is the field strength in dBu, f_H is the upper frequency-limit of the channel, and f_L is the lower frequency-limit of the channel. To calculate the separation distance, i.e. distance beyond r_b where no secondary device can transmit, the distance $r_n - r_b$ such that the signal from the secondary device at r_n results in a signal level of $E_{r_b} - 23$dBu at the TV receiver located at r_b is calculated. For the TV transmitter at Pune, the no-talk radius, i.e. the distance from the tower beyond which a secondary device can use the channel is computed to be 41.60km.

V. Results

The results obtained by TV white space calculation methods of Sec. IV will be discussed in this section.

A. White Space Availability using Pollution, Protection viewpoints & the FCC Rule

Using the methodology described in Sec. III, the pollution and the no-talk radius are calculated for every TV tower in India. Each region is plotted as a circle around the TV tower. Here it has been assumed that each tower has an omnidirectional antenna. The TV white space availability in India using the pollution viewpoint is shown in Fig. 2 and using the protection viewpoint in Fig. 3. White space availability using the FCC regulations is shown in Fig. 4.

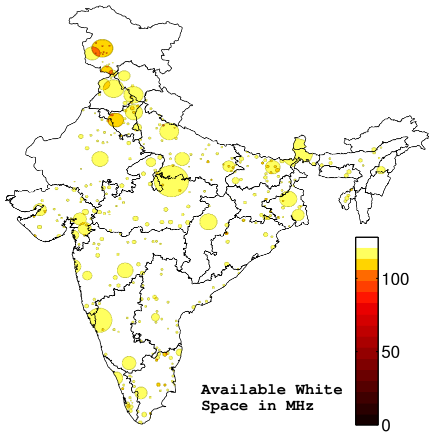

Fig. 3. TV White Space availability using Protection viewpoint $\Delta = 1dB$

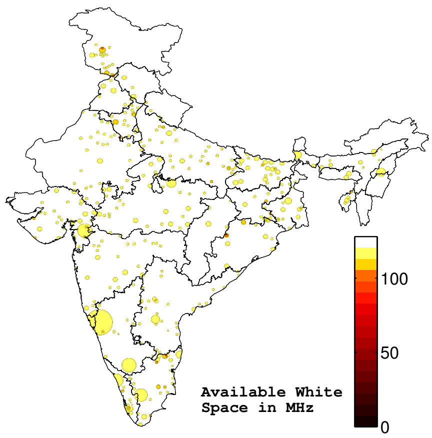

Fig. 4. TV White Space availability using FCC rule

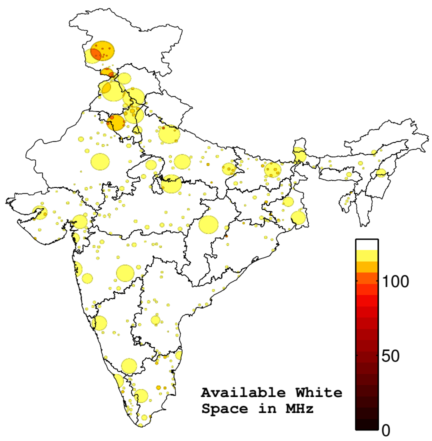

Fig. 2. TV White Space availability using Pollution viewpoint $\gamma = 15dB$

Fig. 2 and Fig. 3 illustrate that at most places in India, not even a single channel in the UHF band is utilized! To quantify this result further, the complementary cumulative distribution function of the number of channels available per unit area as TV white space is plotted in Fig. 5. From the pollution viewpoint with γ = 15dB, 88.82% of the area in India has all the 15 channels available as white space, while in 99.99% of the area, 12 or more channels are available as white space. Similar results are obtained using the protection viewpoint with Ψ = 1 dB which shows that in 78.82% of the area in India, all the 15 channels are available for TV white space secondary operations, and in 99.61% of the area, 10 or more channels are available as white space. With the FCC regulations, which are considered to be conservative (see [5]), 94.97% of the area in India have all 15 channels available for TV white space operations, while in 100% of the area 12 or more channels are available as white space. Table II gives the average number of channels available in the UHF TV bands in across India using different methods described earlier. Conclusions that can be drawn from Table II are as follows:

1) Out of the 15 UHF TV channels (470-590 MHz), the average number of TV channels available for secondary usage is above 14 (112MHz) in every zone of the country.

TABLE II
AVERAGE NUMBER OF CHANNELS AVAILABLE PER UNIT AREA IN EACH ZONE (OUT OF 15 CHANNELS)

Method	**Parameters**	**North Zone**	**West Zone**	**East Zone**	**South Zone**	**North East Zone**	**India**
Pollution Viewpoint	Main channel γ = 5 dB	14.0583	14.0047	14.2313	14.4745	14.8464	14.4175
	Main channel γ = 5 dB, Adjacent Channel γ = 45 dB	14.0430	13.9957	14.2223	14.4693	14.8443	14.4120
	Main channel γ = 10 dB	14.4654	14.6896	14.6295	14.7374	14.9213	14.7340
	Main channel γ = 10 dB, Adjacent Channel γ = 45 dB	14.4558	14.6835	14.6205	14.7322	14.9192	14.7293
	Main channel γ = 15 dB	14.7575	14.8545	14.8214	14.8683	14.9599	14.8750
	Main channel γ = 15 dB, Adjacent Channel γ = 45 dB	14.7478	14.8485	14.8123	14.8630	14.9578	14.8702
Protection Viewpoint	Main channel Ψ = 1 dB	14.8072	14.8830	14.8549	14.8917	14.9673	14.8681
	Main channel Ψ = 1 dB, Adjacent Channel Ψ = 28 dB	14.2821	14.5372	14.4558	14.3666	14.6939	14.5808
	Main channel Ψ = 0.1 dB	14.7784	14.8664	14.8351	14.8782	14.9630	14.8491
	Main channel Ψ = 0.1 dB, Adjacent Channel Ψ = 27.1 dB	14.1757	14.4720	14.8429	14.5745	14.8661	14.5922
FCC Regulations	Main Channel E_{r_b} =41 dBu	14.9506	14.7762	14.6795	14.6510	14.8844	14.9474

TABLE III
NUMBER OF AVAILABLE TV CHANNELS AS A FUNCTION OF PERCENTAGE AREA

Method	**Parameters**	**10 channels free**	**12 channels free**	**15 channels free**
Pollution Viewpoint	Main channel γ = 5 dB	100%	100%	56.49%
	Main channel γ = 5 dB, Adjacent Channel γ = 45 dB	99.99%	99.99%	56.27%
	Main channel γ = 10 dB	100%	100%	78.20%
	Main channel γ = 10 dB, Adjacent Channel γ = 45 dB	99.99%	99.99%	78.05%
	Main channel γ = 15 dB	100%	100%	88.97%
	Main channel γ = 15 dB, Adjacent Channel γ = 45 dB	99.99%	99.99%	88.82%
Protection Viewpoint	Main channel Ψ = 1 dB	100%	100%	88.05%
	Main channel Ψ = 1 dB, Adjacent Channel Ψ = 28 dB	99.61%	99.35%	78.82%
	Main channel Ψ = 0.1 dB	100%	100%	86.41%
	Main channel Ψ = 0.1 dB, Adjacent Channel Ψ = 27.1 dB	99.83%	99.74%	77.74%
FCC Regulations	Main Channel E_{r_b} =41 dBu	100%	100%	94.97%

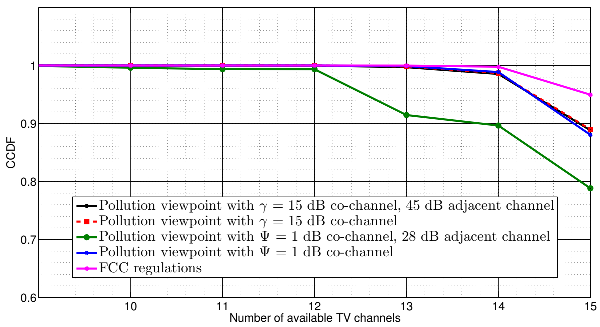

Fig. 5. Complementary cumulative distribution of the available number of channels per area as white space

2) Available TV white space is the maximum in the North East, where 18 transmitters operate in the UHF band.
3) If we use the adjacent channel constraint, the available white space decreases. However, this decrease is less than 1% in each case.

B. Comparison of Indian TV white space Scenario with other countries

Table III concludes that in almost all cases at least 12 out of the 15 channels (80%) are available as TV white space in 100% of the areas in India. This is larger than Japan [8], where out of 40 channels, on an average 16.67 channels (41.67%) are available in 84.3% of the areas. This white space is also larger than what is available in US and the European countries. The available TV white space by area in Germany, UK, Switzerland, Denmark on an average are 19.2 (48%), 23.1 (58%), 25.3 (63%) and 24.4 (61%) channels out of the 40 channels respectively [7]. Similarly, as compared to the US, the available TV white space in India is much larger. It must be noted that in TV white space studies across the world, the IMT-A band is also included.

VI. PROPOSED CHANNEL ALLOCATION SCHEME

There are a total of 376 Doordarshan TV transmitters in India illustrated in Fig. 6 operating in the 470-590MHz. Currently, in four of the five zones, 14 out of the 15 channels (channels 21-34) are *sparsely* used for transmissions. As shown in Fig. 6, channels allocated to the transmitters are reused inefficiently or at very large distances. For instance, out of the 376 transmitters, only 34 transmitters in India operate on channel 21. We propose a channel allocation scheme such that the minimum number of TV channels are used in each zone, while ensuring that the coverage areas of different transmitters do not overlap. The algorithm of the proposed channel allocation scheme is as follows.

Using the algorithm described above, the minimum number of distinct channels required without any overlap of the coverage areas in India is given in Fig. 7. Under this channel allocation scheme, the maximum number of distinct TV channels required in the entire zone is eight, which is smaller than the fourteen channels currently being used. To avoid adjacent channel interference, the overlapping channels must be non-adjacent.

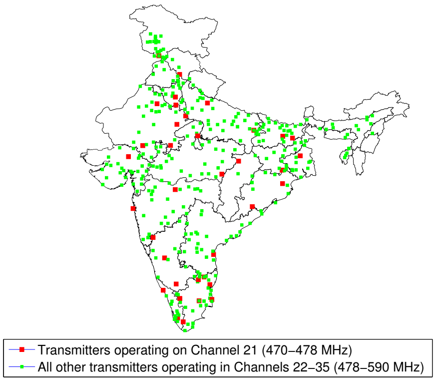

Fig. 6. TV Transmitters operating in UHF Band-IV (470-590MHz)

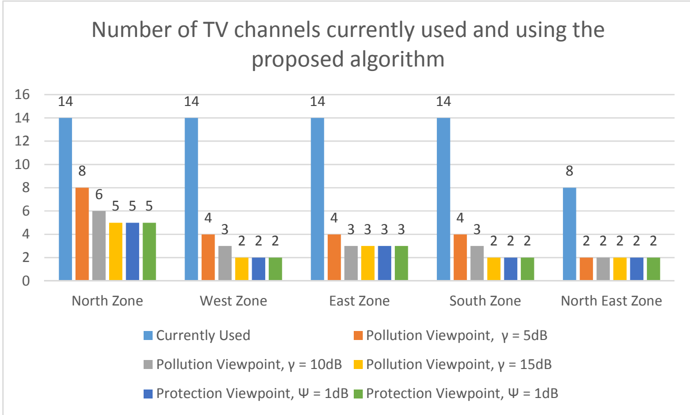

Fig. 7. Number of channels required in currently and after using the proposed algorithm

for *All transmitters in India ;*
do
  Check if coverage areas of adjacent transmitters overlap;
  if *Overlap* **then**
    Check channel numbers of overlapping transmitters;
    if *Channel numbers are same* **then**
      Change operating channel of one tower;
      Calculate coverage area of towers with new operating channels;
    else
      exit
    end
  else
    exit
  end
end

VII. Conclusions

In this paper, quantitative analysis of the available TV white space in the 470-590MHz UHF TV band in India was performed. It is observed that unlike developed countries, a major portion of TV band spectrum is unutilized in India. The results show that even while using conservative parameters, in at least 56.27% areas in the country, all the 15 channels (100% of the TV band spectrum) are free! The average available TV white space was calculated using two methods: (i) the protection and pollution viewpoints [5]; and, (ii) the FCC regulations [11]. By both methods, the average available TV white space in the UHF TV band was shown to be more than 100MHz! An algorithm was proposed for reassignment of TV transmitter frequencies to free up unused spectrum. It was observed that eight TV channels (or 64MHz) are sufficient to provide the existing UHF TV band coverage in India.

In the future, we wish to explore suitable regulations in India for the TV white space to enable affordable broadband coverage. This is timely and important since policy intent for TV white space was made in NFAP 2011.

References

[1] M. Islam et. al, “Spectrum survey in Singapore: Occupancy Measurements and Analyses,” in Proc. of 3rd Intl. Conference on Cognitive Radio Oriented Wireless Networks and Communications, May 2008, pp. 1-7.
[2] R. Chiang, G. Rowe, and K. Sowerby, “A Quantitative Analysis of Spectral Occupancy Measurements for Cognitive Radio,” in Proc. of IEEE 65th Vehicular Technology Conference, Apr. 2007, pp. 3016-3020.
[3] M. McHenry et. al, “Chicago Spectrum Occupancy Measurements & analysis and a Long-term Studies Proposal,” in Proc. of the ACM 1st Intl. Wkshp. on Tech. and Policy for Accessing Spectrum, Aug. 2006, pp. 1-12.
[4] M. Lopez-Benitez, A. Umbert, and F. Casadevall. “Evaluation of Spectrum Occupancy in Spain for Cognitive Radio Applications,” in Proc. of IEEE 69th Vehicular Technology Conference, Apr. 2009, pp. 1-5.
[5] S. Mishra, and A. Sahai, “How much white space is there?,” Tech. Report UCB/EECS-2009-3, EECS Department, UC Berkeley, Jan. 2009: http://www.eecs.berkeley.edu/Pubs/TechRpts/2009/EECS-2009-3.html.
[6] M. Nekovee, “Quantifying the Availability of TV White Spaces for Cognitive Radio Operation in the UK,” in Proc. of IEEE Intl. Conf. on Communications Workshops, Jun. 2009, pp. 1-5.
[7] J. van de Beek et. al “TV White Space in Europe,” in IEEE Trans. on Mobile Computing, vol.11, no.2, Feb. 2012, pp. 178-188.
[8] T. Shimomura, T. Oyama and H. Seki, “Analysis of TV White Space Availability in Japan,” in Proc. of IEEE Vehicular Tech. Conf., Sep. 2012.
[9] P. Kumar et. al, “White Space Detection and Spectrum Characterization in Urban and Rural India,” in Proc. of IEEE 14th Intl. Symp. and Wkshops on a World of Wireless, Mobile and Multimedia Networks, Jun. 2013, pp. 1-6.
[10] S. N. Merchant, M. Z. A. Khan, “High Performance Cognitive Radio Networks,” Project Report submitted to the PRSG Review (Private Communication).
[11] US Federal Communication Commission, “Second Report and Order and Memorandum Opinion and Order,” Tech. Rep. 08-260, Nov. 2008.
[12] Ofcom, “Digital dividend: cognitive access. Consultation on license-exempting cognitive devices using interleaved spectrum,” Feb. 2009. http://stakeholders.ofcom.org.uk/binaries/consultations/cognitive/statement/statement.pdf
[13] “National Frequency Allocation Plan 2011, WPC, Department of Telecom., Govt. of India,” http://www.dot.gov.in/as/Draft%20NFAP-2011.pdf
[14] M. Hata, “Empirical Formula for Propagation Loss in Land Mobile Radio Services,” in IEEE Trans. on Vehicular Technology, vol.29, no.3, Aug. 1980, pp. 317-325.
[15] M. V. S. N. Prasad, and I. Ahmad. “Comparison of some path loss prediction methods with VHF/UHF measurements,” in IEEE Trans. on Broadcasting, vol.43, no.4, Dec. 1997, pp. 459-486.
[16] US FCC, “Longley-rice methodology for evaluating TV coverage and interference,” OET Bulletin 69, Feb. 2004.