White Space Detection and Spectrum Characterization in Urban and Rural India

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Abstract—**Broadband penetration in developing countries such as India is still very low, especially in rural areas, because of the prohibitive cost of laying cable and fiber. Recently, wireless solutions based on Wi-Fi have been proposed as a cost-effective solution to bridge the last-mile problem. However, Wi-Fi normally operates in the 2.4 GHz band and above, where signal propagation is not as good as in sub-GHz bands such as terrestrial TV bands. Using TV white spaces for broadband connectivity can be game changing, bringing down the cost of such networks to an affordable level. Few studies exist, however, which characterize sub-GHz spectrum usage in India.**

In this paper, we make two main contributions. First, we present results of several day-long spectrum measurements in the sub-GHz band made at different urban and rural locations in the National Capital Region (i.e. near New Delhi) of India. Second, we have developed an inexpensive spectrum measurement setup based on a commercially available hand-held spectrum analyzer called RF Explorer. Our main findings are that about 85% of the TV band in the 470-698 MHz range are not used in the heart of urban Delhi, and as much as 95% are unused in rural areas. At any point in time, the largest contiguous TV white space varies between 66 MHz to 136 MHz in an urban location, and between 51 MHz and 242 MHz in a rural location. This suggests the need for development of very wideband, and low-cost wireless solutions which can exploit these valuable white spaces to provide affordable rural connectivity.

I. Introduction

Infrastructural voids have long prevented developing countries like India from providing network connectivity to their geographically dispersed rural areas. Although extensive work is being done to establish such network links based primarily on 802.11 hardware which utilizes ISM bands, very little effort has been made to use under-utilized licensed spectrum (White Spaces) for this application. These White Spaces in the spectrum hold enormous potential for meeting the growing demands of wireless connectivity, particularly because of their excellent propagation characteristics. Spectrum studies clearly show the feasibility of using these White Spaces to allow secondary communication [1], [2]. Whereas, Opportunistic Spectrum Utilization based on White Spaces has been implemented in the US (under prescribed rulings of the FCC) [3] and in the UK (under rulings of Office of Communications, UK's independent communications regulator) [4] , developing nations are still at a nascent stage of white space research .

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In India, wireless licenses are allotted by the Wireless Planning and Coordination (WPC) wing of the Ministry of Communications and Information Technology. The national frequency allocation plan (NFAP) published by the WPC gives a high-level overview of which bands have been allocated for which purpose [5]. Detailed geographic-specific information about which agencies have been allocated spectrum is, however, not publicly available.

What is well known is that a single agency, Doordarshan, a public service broadcaster that has editorial control by 'Prasar Bharti' and whose board members are appointed by Government of India, has exclusive use of terrestrial TV bands. Doordarshan today has more than 1400 terrestrial transmitters across the geographical expanse of the country. Currently, two channels, DD National and DD News are terrestrially transmitted as 'all-India channels'. As a part of the digitization process, Doordarshan plans to completely digitize its terrestrial transmission by end of 2017 [6]. However, no finite time frame has been decided for stopping the analog transmission and it will continue along with the digital transmission till a substantial percentage of the population switches over to a digital mode of reception.

Doordarshan transmitters functioning across India can be classified according to the bands allocated to them. There are primarily three bands, VHF Band-I, VHF Band-II and UHF Band-IV. Transmission schedule for Doordarshan is from 0530 (Indian Standard Time) to midnight and may extend beyond this time, if necessary. The VHF Band-I extends from 54-68 MHz and comprises 2 analog TV channels, VHF Band-II extends from 174-320 MHz and comprises 8 channels and UHF Band-IV extends from 470-582 MHz and comprises 14 channels. Whereas the former two bands have a bandwidth of 7 MHz, the latter is spread across 8MHz. Frequencies from 585-698 MHz is allotted to mobile TV broadcast services.

Few studies have been published of spectrum usage in India and other developing countries, thereby leaving several important questions, such as the following, unanswered.

- How much spectrum in the sub-GHz band is unused in rural and urban settings?
- At any given point of time, how much contiguous white space is available?
- Should developing countries adopt TV white space

databases as has been done in developed nations?

In this paper, we attempt to answer some of these questions. We present results of several day-long spectrum measurements in the sub-GHz band made at three different locations in the National Capital Region (i.e. near New Delhi) of India. One site is at the campus of I.I.T. Delhi, located in the heart of urban south Delhi. Another site is a semi-urban region. The third measurement site is in the outskirts of Delhi, in a rural location. We thus attempt to create a spectrum map that encompasses variations in time and location.

We also develop an economical spectrum sensing solution which can be used in White Space Networks. Our setup consists of a laptop along with an inexpensive spectrum analyzer, RF Explorer. The RF explorer by default is operated manually. Since this is undesirable for long-term spectrum measurements, we developed software to automate spectrum measurements using this device.

The rest of the paper is organized as follows. In Section II we discuss our experimental setup and various locations under consideration. In Section III, the results are analyzed and spectrum is characterized for rural and urban locations. Section IV talks about related work. The paper culminates in section V with conclusions and future work.

II. Background Preliminaries

In this section, we describe our experimental setup, the automation scripts and algorithms we developed for spectrum measurements, and specifics of the geographic locations of measurement sites.

A. Experimental setup

1) RF Explorer: This device is a handheld digital spectrum analyzer based on a highly integrated frequency synthesizer which offers high performance, compact size, low consumption and low cost. It is currently available at $129 online [7].

We used RF Explorer model WSUB1G. This model comes with a Nagoya NA-773 wideband telescopic antenna. It has wide band measurement capability in all popular sub-GHz ISM bands, including 433 MHz and 915 MHz, UHF TV, 70 cm and 33 cm HAM radio, GSM, etc. Any frequency from 240 MHz to 960 MHz can be analyzed. It can be optionally connected to a Windows PC USB port for additional functionality using the "RF Explorer Windows PC Client" tool which supports Windows XP/Vista/Win7 both 32 and 64 bits. It is based on a powerful Microchip 16 bits microcontroller: PIC24FJ64GA004. The RF section is a sub-GHz Si4432 transceiver, which offers receiver and transmitter features. Our unit does not include the RF Generator functionality; only the Spectrum analyzer functionality is available in it. Prior to experiments, device was connected directly to signal generator and results were observed at different frequencies and power levels. Error was ± 2 dBm which is in compliance with error mentioned in data sheet. More details can be found from the RF Explorer technical specifications [7].

2) Automation: We wanted RF Explorer to repeatedly scan the spectrum from 240 to 960 MHz for 24 hours. However, since RF explorer is designed to be configured manually, with a maximum scanning range of 100 MHz, it was required to automate the spectrum measurements by using scripts. We automated the RF Explorer Windows PC client tool which we configured to do the following. It begins scanning from 240 MHz in bands of width 20 MHz. Each band is scanned 28 times after which the tool shifts to the next 20 MHz band and so on. The time taken for scanning the bands may vary depending upon the presence of signal in the band and thus it takes approximately 272 to 288 seconds to scan the whole band from 240 MHz to 960 MHz. The frequency resolution in the experiments is 178.6 KHz.

3) Algorithm used for automation: The PC client sends start frequency, end frequency and frequency span to the RF Explorer. RF Explorer senses and returns power value which is saved along with the corresponding frequency and time stamp in CSV format. After connecting the RF explorer, an event automatic_ button_ Click1() is triggered by clicking on 'automatic' button and worker_ DoWork() is called to control RF Explorer. Details are given in Table 1.

TABLE I. RF Explorer Automation Steps

```
# Function work_ DoWork( )
Call UpdateRemoteConfigData( )

# Function UpdateRemoteConfigData()
max_ frequency=960; fStartFreq=240; fspan=20; i=0;
1. While i < 360 repeat step 2 to 7
2. fEndFreq = fStartFreq + fspan;
3. While (fEndFreq <= max_ frequency) repeat step 4 and 5.
4. Send command to RF Explorer device.
5. fStartFreq = fStartFreq + fspan;
fEndFreq = fStartFreq + fspan;
6. Get current date time of the system and path where output files will be saved.
Concatenate path and time to file name.
7. Call function SaveFileCSV.

# Function SaveFileCSV (string Filename, double start_ freq, double end_ freq)
1. Get current time in hour, minute and second form.
2. Calculate time = hour + minute/60.0 + second/3600.0;
3. Write received string values in CSV file along with time at which they were received.
```

B. Measurement locations

Using the automated system developed, 24-hour long spectrum measurements were taken from 240 MHz to 960 MHz at various locations in the NCR area. Regions selected for our experiments are urban south-west region (IIT Delhi), semi-urban region of north-west Delhi (Sultanpuri) and a rural region at the outskirts of Delhi (Katewara village). The experimental locations are shown on the map depicted in Figure 1

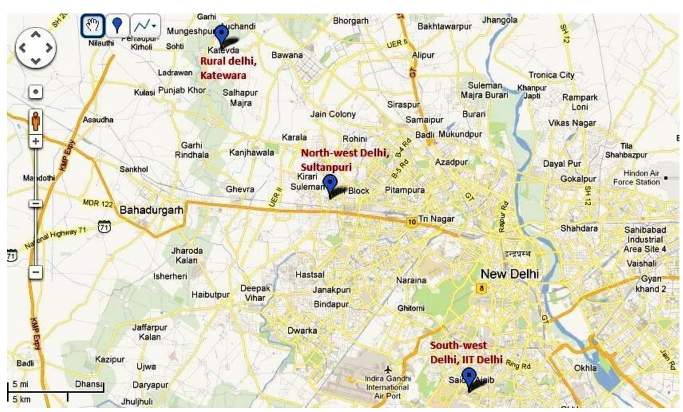

Fig. 1. Locations considered for measurement(courtesy: Google maps)

III. Observation and Analysis

We plot the observed power levels at different frequencies during different times of the day at the different urban and rural locations. We use two metrics: "power level cumulative distribution" and "maximum contiguous bandwidth available" to compare the results at different geographical locations.

A. *Time-frequency spectrum utilization*

To analyze the frequency usage, graphs are plotted between time and frequency. Power levels are denoted using the following colors : black for more than -70 dBm, red for -70 to -80 dBm, magenta for -80 to -90 dBm, blue for -90 to -100 dBm, cyan for -100 to -110 dBm and yellow for less than -110 dBm. All power levels presented are the power levels per 178.6 KHz of bandwidth.

The sensing results for IIT Delhi (Figure 2) shows that most of the bands which are observed for stronger signals, are used throughout the day. According to National Frequency Allocation Plan (NFAP), among the bands observed in graph 260.3 MHz to 260.8 MHz, 292.8 MHz to 294.5 MHz and 313 MHz to 320.5 MHz are used for mobile satellite services. Bands from 356.3 MHZ to 357.3 MHz, 362.2 MHz to 363.2 MHz, 363.7 MHz to 364.3 MHz and 367.5 MHz to 368.5 MHz are allotted for mobile satellite services and digital radio trunked service for captive networks. 390 MHz to 390.6 MHz, 392.4 MHZ to 393.6 MHz and 395.1 MHz to 396 MHz is used for digital radio trunked system and mobile satellite services. Frequencies from 420 MHz to 434 MHz and 438 MHz to 441 MHz are most crowded and are allotted to many users. These are used for radio-location service, aeronautical radio navigation, digital trunked radio and digital seismic telemetry. Bands from 470 MHz to 477 MHz and 510 MHz to 518 MHz, where we observe the presence of signals, are allotted for terrestrial TV transmission and fixed and mobile TV services. The signal in the first band (470-477MHz) is very faint and seems to be coming from TV tower located at a large distance. There is no transmission in second band (510-518MHz) from 2:00 am to 4:30 am (Indian Standard Time). Frequencies from 602.8 MHz to 607.2 MHz, 622.2 MHz to 624 MHz and 611.5 MHz to 614.2 MHz are used for digital broadcasting services including Mobile TV, where as the latter is also used for radio astronomy service. The band from 717 MHz to 724 MHz is allotted for fixed and mobile broadcasting, radio navigation and radio astronomy. Dark colour bands seen above 800 MHz are allotted for CDMA and GSM services. Apart from these bands whole of the spectrum has power level below -110 dBm. Our measurements using RF Explorer reveal that on any channel occupied by a Primary User, the ambient noise level in absence of any transmission is -115 to -117 dBm. This was confirmed by us through repeated measurements in known vacant channels. Keeping sufficient cushion for low power transmissions, we chose -110 dBm as the noise threshold for our measurements.

Similar bands are observed in Figure 3 for North-west Delhi area with lower power levels. In rural areas (Figure 4), these signal levels become much fainter and some bands disappear completely. Consider the 510-518 MHz TV band for example, which is available only in metropolitan areas, and hence appears very faint in the rural site. In rural areas no signal is observed in 600 MHz range throughout the day and in north-west Delhi also it has very low power level.

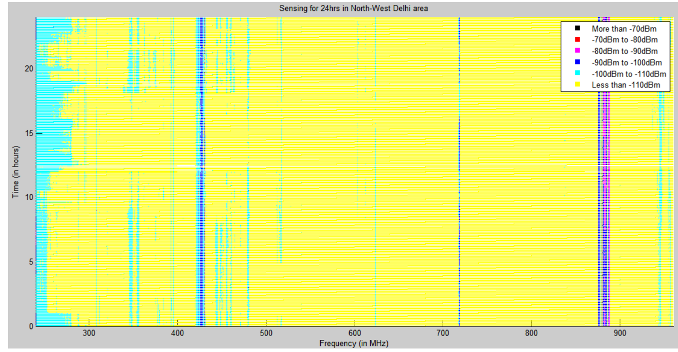

Fig. 3. Sensing in North-west Delhi area for 24 hours

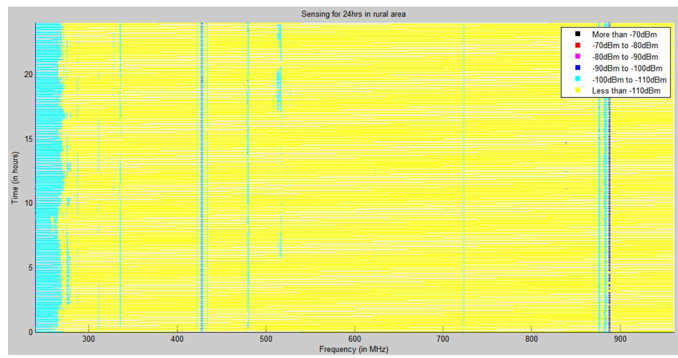

Fig. 4. Sensing in Rural Delhi for 24 hours

Many frequencies are observed to be used for digital radio trunk services and mobile satellite services in areas adjoining IIT Delhi area and north-west Delhi, however no such bands appear in rural areas. Cellular bands also show very low power levels at the rural site.

B. *Urban vs. rural spectrum characteristics*

We use two metrics for comparing spectrum availability in different locations. The first, "cumulative power distribution", is obtained by computing the cumulative distribution of power levels in all time-frequency bins within a particular frequency band of concern. For example, to obtain the cumulative power distribution in the TV band, we take all power measurements in the frequency band 470 - 698MHz over a time duration of a day, and compute the cumulative distribution of this data.

The second, "maximum available contiguous bandwidth" in the TV band is the largest contiguous frequency band in which no three consecutive frequency bins have power level larger than the noise threshold. Essentially this quantity represents the largest TV white space band available. We choose the number three to take care of the spurious cases of large random noise values occurring rarely at some frequencies. Note that a single TV channel overs at least 6MHz of bandwidth which corresponds to 33 consecutive frequency bins. Thus one or two isolated large power levels are likely due to noise and not due to the presence of a TV signal.

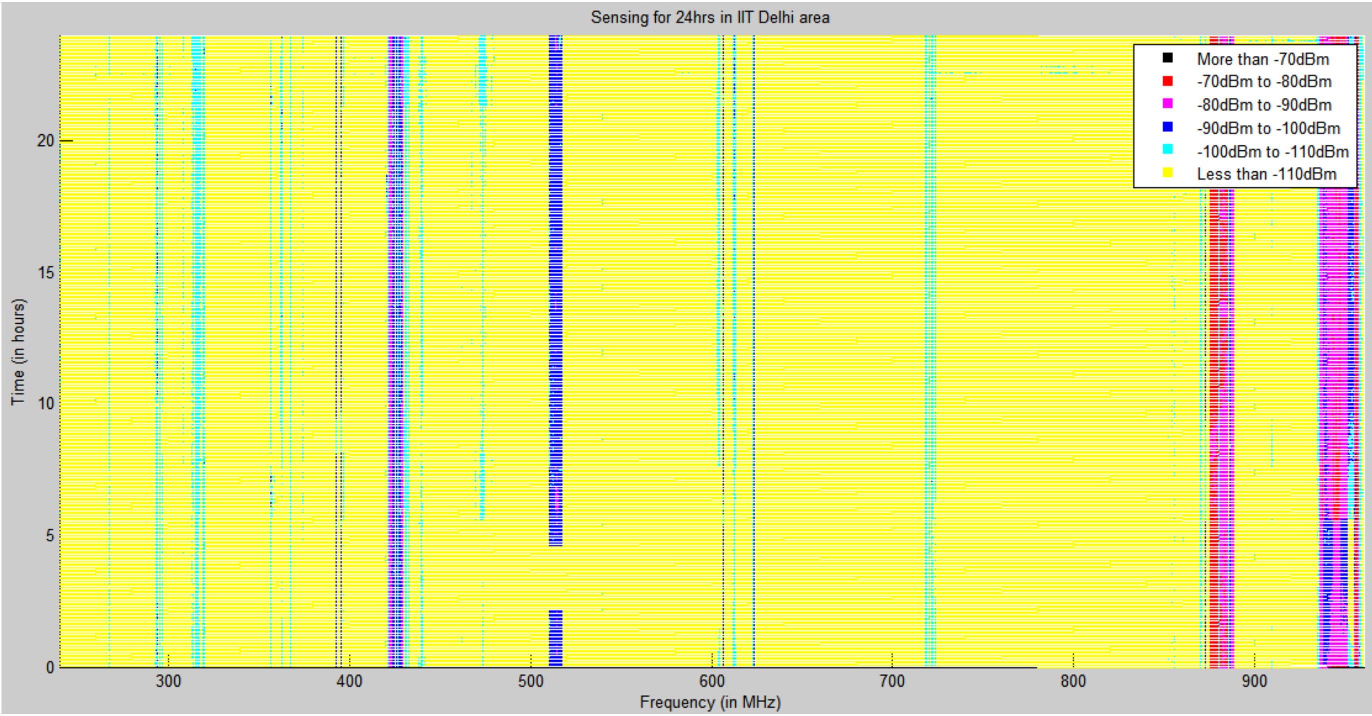

Fig. 2. Sensing at IIT Delhi for 24 hours

1) Power level distribution: Considering -110 dBm as the noise threshold level for TV bands, we obtained 24 hour cumulative distribution of power levels. As shown in Figure 5, at IIT Delhi, 85.89% of frequencies have power levels less than the threshold. This value comes out to be 91.67% for North-west Delhi area and 94.92% for the rural Delhi location. It shows that this percentage of the spectrum is not used by any service provider.

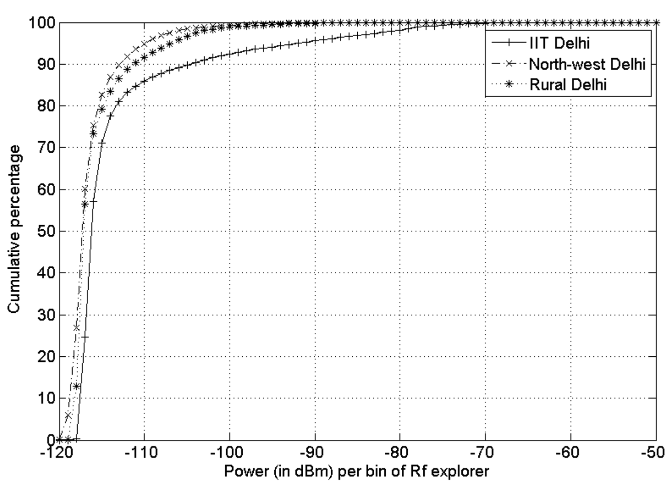

Fig. 5. Cumulative distribution of power(TV band,470-698 MHz) for 24 hours

As shown in Figure 6, if these power distribution graphs are plotted for the entire spectrum (260 - 940 MHz), 84.1% signals for IIT Delhi, 85.55% signals for north-west Delhi and 90.12% signals for rural area have a power level less than -110 dBm. These plots show that spectrum is less occupied at the rural site when compared to the urban sites.

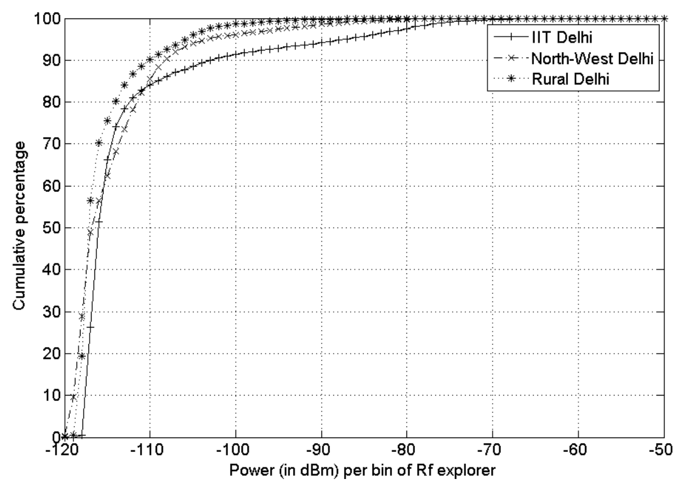

Fig. 6. Cumulative distribution of Power (240-960 MHz) for 24 hours

2) Maximum available contiguous bandwidth: In IIT Delhi, the smallest value of maximum available contiguous bandwidth is 66 MHz and the largest is 136 MHz. Figure 7 shows that there is very little change in usage of spectrum in this area throughout the day. However, in north-west region this quantity is more distributed ranging from 93 MHz to 156 MHz (Figure 8), showing availability of larger white spaces when compared to IIT Delhi. In rural area bandwidth availability is very dynamic and ranges from 51 MHz to 242 MHz (Figure 9). This continuous change in available bandwidth is because we get a very faint TV signal in the rural location whose signal level is close to our chosen noise threshold. A continuous fluctuation in this signal results in such a wide fluctuation of the largest available white space. This observation is for a rural area which is near to a large city. We speculate that rural regions in more remote areas from urban areas will have even smaller spectrum occupancy and larger white spaces than the location recorded here.

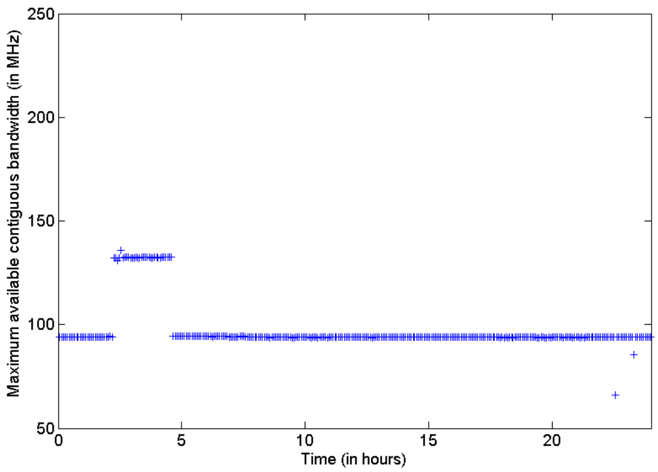

Fig. 7. Maximum available contiguous bandwidth in TV band for IIT Delhi

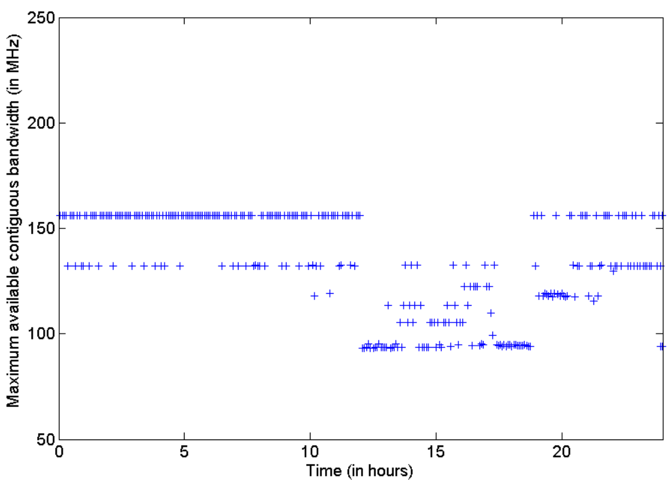

Fig. 8. Maximum available contiguous bandwidth in TV band for North-west Delhi

IV. Related work

Yanfeng Han et al. [8] have measured spectrum occupancy using Rohde & Schwarz FSU-8 spectrum analyzer in Chengdu, China. Experiments were conducted at a single location only - the highest building (in the sampling vicinity), for a week to show spectrum occupancy i.e. how TV frequency spectrum changes with time. Another study [9] has shown that there is less unused TV spectrum available in Europe compared to US. This study of TV spectrum characteristics and White Space in 11 European counties and US shows that average of 56% of White Space by area is available in Europe, which is 79% in US. However, if restrictions are applied to the use of adjacent TV channels, these values reduce to 25% and 18% respectively.

SpecNet [10], a programmable distributed spectrum sensing platform, provides measurement studies in Bangalore,

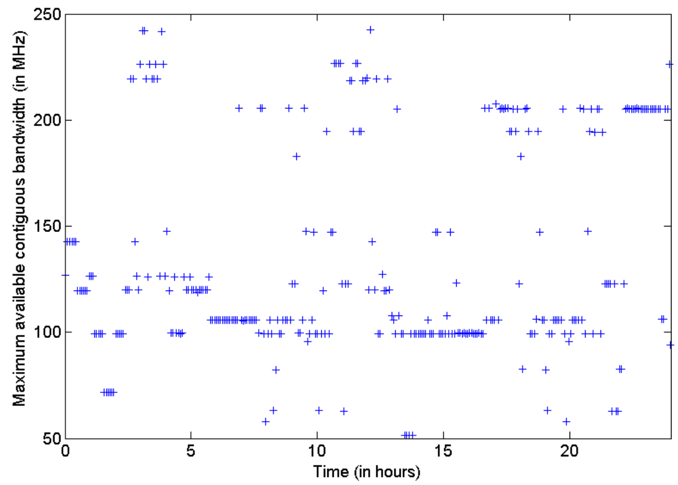

Fig. 9. Maximum available contiguous bandwidth in TV band for Rural Delhi

India. It aimed to provide networked spectrum analyzers around the world for spectrum measurements but it has a limitation of using expensive equipment for spectrum analysis. Unlike our work, the focus of the SpecNet paper was on system development and less on making extensive spectrum measurements in India. The study revealed that in Bangalore over 90% of the spectrum remains unused in the sub-gigahertz spectrum and only 16 out of 566 MHz of TV spectrum is being used. We conducted spectrum measurements in TV bands in rural and urban regions of Delhi NCR. Compared to SpecNet, our measurement setup is fairly inexpensive and portable, and is thus better suited for widespread use in developing countries. Moreover, we have conducted experiments for longer contiguous periods of 24 hours and more.

A study in Singapore [11] was carried out for the 24-hour spectrum usage pattern in the frequency bands ranging from 80 MHz to 5850 MHz to find the utilization of scarce radio spectrum allocated to different services and to identify the bands that could be accessed for future opportunistic use. The average spectrum occupancy for the whole range of frequency i.e. frequency bands ranging from 80 MHz to 5850 MHz was found to be only 4.54%. The results, taken over 12 weekday periods, revealed that a significant amount of spectrum in Singapore has very low occupancy at all times. Various other spectrum analysis have been conducted in other parts of the world [12], [13]. A common finding of all the studies done in spectrum characterization is that large portion of TV spectrum is underutilized.

V. Conclusion and future work

TV White Spaces that emerged as a result of digitization of analog TV transmission have become a center of immense research to unlock the potential of unused wireless spectrum. In the NCR region in India, we find that most TV bandwidth is unused, even without digitization. The digitization of TV transmissions is underway and may free up even more TV spectrum.

Our study focused on detection, verification and profiling of TV White Spaces in the National Capital Region (NCR) of India. We measured the signal strength characteristics of transmissions in the band from 240 MHz to 960 MHz in the geographical area under our scope of study. We then went on to characterize spectrum usage when compared between rural and urban areas of NCR. To the best of our knowledge, our work is the first attempt to profile the spectrum and deduce trends in spectrum characteristics at various locations in urban and rural India.

Note that the NCR region likely represents one of the most heavily spectrum-crowded regions in India. We expect even more white spaces in the sub-GHz band to be available in other urban and rural parts of the country. As part of future work, we will analyze spectrum usage in various villages and towns in the country.

As our ongoing work, we are developing an application that overlays the geographical area of NCR with a spectrum database and defines "non-interference" energy thresholds. This application would allow a secondary user to point at a location on Map and generate a Spectrum Graph that shows the available White Spaces in his vicinity. It would also provide him permissible values for the maximum "secondary transmission signal strength" for that region thereby enabling him to set up a White Space Network.

ACKNOWLEDGEMENT

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