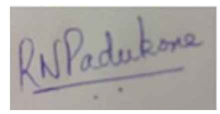
To: The Adviser (Network, Spectrum & Licensing)
TRAI, New Delhi.

Dear Sir,

This is with reference to your Request for Comments with regard to Consultation Paper on "Delivering Broadband Quickly: What do we need to do?".
The necessary comments are enumerated below as desired.

Thanking you,

Yours faithfully



(R. N. PADUKONE)

Comments on Issues for Consultation (TRAI)

Q1. What immediate measures are required to promote wireline technologies in access networks? What is the cost per line for various wireline technologies and how can this cost be minimised? Please reply separately for each technology.

A1. **Wire line technologies**: Wireline technologies, also called DSL technologies, are practically limited to distribution within the campus of the user or say, within a multi-storied building. Though the range may extend to about 3 km, the cost of copper and the cost of laying cables including right of way (ROW) etc. does not make it a feasible proposition for a new operator to adopt this technology in the access network. It is noteworthy to mention the dire need for Single-Window Approach for securing ROW as a substantial means of reducing costs by way of time overruns and other associated inefficiencies.

Cable technologies: The other wireline technology is the cable network. If the govt mandates that all cable networks operate in dual bidirectional mode (today amplifiers are uni-directional) this would increase broadband connectivity wherever cable networks are available. Govt should also mandate the use of open set-top-box that allows the customer to exercise his own choice of broadband service provider. This is also discussed under Q13 below.

Fibre technologies: This is a land line technology as distinct from wire line technology, and has the advantage of being able to transport huge bandwidths. However, setting up Fibre to the Panchayats in rural areas will entail huge costs both during installation as well as during maintenance phases. In addition, the fibre model will be prone to ownership and sharing issues. Using wireless spectrum for rural coverage will reduce the Digital India costs by several orders of magnitude. There is no simple measure to address the cost disadvantage suffered by fibre in the rural setting. Wireless however can provide the rural citizen with a simple and viable alternative, and could redeem him from for the handicaps he suffers in comparison to the citizen in urban areas in the form of larger coverage distances coupled with extremely low user densities.

Q2. What are the impediments to the deployment of wireless technologies in the access network? How can these deployments be made faster? Please reply separately for each technology.

A2. Serious impediment to deployment of wireless technologies in access networks exists in rural areas which are saddled with large distances of about 30 kms over vast open tracts of land, whereas the allotted spectrum frequencies for 2G/3G/4G mobile can service only a fraction of these distances. This kind of limitation is there also in the hilly and thickly forested areas of the North East where the 2G/3G/4G spectrum is not effective in reaching the remote areas. The UHF band is thus more suited for covering sparse populations in such terrain. The large number of mobile transmitters required at available spectrum frequencies in 2G/3G/4G for full coverage coupled with low user densities makes the communication business virtually impossible from financial viability point of view. To overcome this impediment, it is necessary for the policy maker to consider allotting specific frequency bands in the spectrum in rural areas that can provide the required coverage of 30 km.

The sub-GHz band (UHF band) between 400 MHz and 700MHz also referred to as TV White Spaces (TVWS) is the ideal candidate for fulfilling this requirement. From technology point of view, the future of true broadband lies in adopting the OFDM technology in the access network which provides high spectral efficiency and carrier capacities. Also, by coupling this with WiFi and its associated mesh technology, very cost effective solutions can be configured for covering distributed population clusters in villages and the connecting transport routes such as road and rail. Considering the severity of digital divide that separates the rural from the urban and the need to adopt a balanced approach in making best possible use of the available technologies such as OFDM, etc. and **a combination of licensed and unlicensed bands defining broadband spectrum policy that provides for certain appropriate bands specific to urban and rural use respectively – for licensed operations in 4G Mobile services, backhaul applications and TV mobile broadcast – as well as another band for unlicensed but regulated operations exclusively for rural areas.** Such a wholistic approach will ensure immense amount of flexibility from user point of view.

Apart from FCC in the USA, the following countries/organizations have also taken initiative in opening up TVWS spectrum:

- United Kingdom (OFCOM)
- Japan (NICT)
- Singapore (I2R)
- South Africa (ICASA)
- Korea (KCC)

TVWS spectrum allocation presents a unique opportunity to India to take a lead in positioning broadband to drive National GDP. Hence it is time for India to take the necessary leap. One can say that this is India's moment to demonstrate technological leadership which has hitherto been latent, just for want of a credible government policy.

Indeed, it does India proud, to note that high quality academic paper has been produced by Gaurang Naik, Sudesh Singhal, Animesh Kumar, and Abhay Karandikar of the Department of

Electrical Engineering, Indian Institute of Technology Bombay to make **"a quantitative assessment of TV white spaces in India".** The paper is attached herewith for reference. Comprehensive quantitative assessment and estimates for the TV white space in the 470-590MHz band for four zones of India (all except north) are 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 these four zones is calculated using two methods: (i) the primary (licensed) user and secondary (unlicensed) user point of view; 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 allocation scheme is presented which results in insignicant interference to the TV receivers while using the least number of TV channels for transmission across the four zones. Based on this reassignment, it is found that four TV band channels (or 32MHz) are sufficient to provide the existing UHF TV band coverage in India.

Q3. The recommendations of the Authority on Microwave backhaul have been recently released. Are there any other issues which need to be addressed to ensure availability of sufficient Microwave backhaul capacity for the growth of broadband in the country?

A3. The issue of licensing UHF band in rural areas as pointed out under Q2 above for backhaul application as one of the bottlenecks that must be addressed may kindly be considered.

Q4. The pricing of Domestic Leased Circuits (DLC) have been reviewed in July 2014. Apart from pricing, are there any other issues which can improve availability of DLC?

A4. DLC over ultra high Microwave frequency (60GHz and near about) can be an innovative media in the urban areas, especially where there are tall buildings. Government should be liberal in promoting such solutions by giving prompt permissions for pilot deployment and necessary custom clearances, etc. Attractive licensing terms and conditions for such spectrum must be considered by the government on a proactive basis.

Q5. What are the specific reasons that ISPs are proactively not connecting with NIXI? What measures are required so that all ISPs are connected to the NIXI?

A5. One of the important reasons why ISPs are not connecting to NIXI could be lack of sensitivity to provide quality of service to the customer. Maybe, lack of awareness on the part of ISPs also could be a factor. Information dissemination of the quantitative enhancement of quality parameters (such as packet delay, etc.) can motivate the ISPs to connect to NIXI. Hence some marketing effort by NiXi can improve the situation.

Q6. Would the hosting of content within the country help in reduction of the cost of broadband to a subscriber? If yes, what measures are required to encourage content service providers to host content in the data centre situated within India?

A6. Technically speaking, hosting of content within the country will certainly help in reduction of the cost of broadband to a subscriber. However, little can be achieved practically by the government by way of encouraging content service providers to host content in the data centre situated within India as it is a very slow process.

A speedier and innovative approach would be to regulate content in a way that opens up the very architecture of end devices and set top boxes, to themselves act as content distributors. This approach would enable content to flow freely and be available in clusters where it is most required. To implement this, India would have to take a lead in standardizing the content addressing scheme **and this would enable India to be virtually a global leader of Content distribution**, much the same way as USA is a global leader in the field of Internet addressing. If the regulatory authority is open to such proposal, a detailed presentation can be made on the subject for its kind consideration.

Q7. Are PSUs ideal choices for implementing the National Optical Fibre Network (NOFN) project?

A7. No, in principle, Government should restrict itself to the business of governance and policy making. As a corollary, sooner the PSUs are privatized (as was done in the case of VSNL), the better. Such a move will permit Indian industry to compete globally without having to tolerate inefficiency constraints.

Q8. Should awarding of EPC turnkey contracts to private sector parties through International Competitive Bidding (ICB) be considered for the NOFN project?

A8. This seems to be a feasible option.

Q9. Are there any ways in which infrastructure development costs can be reduced? Is it possible to piggyback on the existing private sector access networks so as to minimize costs in reaching remote rural locations?

A9. Laying fiber to all gram panchayats will be a huge cost. Using unlicensed spectrum will reduce the Digital India costs by several orders of magnitude if we take into account both installation and future maintenance costs.

Piggybacking on the existing private sector access networks to minimize costs in reaching remote rural locations does not seem to be a feasible solution and is fraught with endless regulatory issues between the concerned players.

Infrastructure development costs in the rural segment however can be reduced considerably by exploring appropriate spectrum bands that are capable of providing coverage of at least 30 kms in typical rural stretches as elucidated under Q2**.** The unused and hitherto **wasted spectrum** in UHF band of 400 MHz to 750 MHz once used for analog TV broadcast (also referred to as TV white spaces in the USA), can meet this requirement in good measure. This is the simplest way to extend broadband in rural areas at least cost thereby bridging the digital divide.

It must be appreciated that spectrum is a natural resource like water and air. The rural citizen has always been handicapped by having to contend with large stretches of distances coupled with low teledensity, both of which make access to communication facility a very costly affair compared to urban areas. Considering this, a case is made out to dedicate a portion of the UHF band for use in rural areas in the form of unlicensed band. The USA has already taken the first steps in this regard and India can tweak the US experience to its own special requirements. Thus in principle, some band in the said UHF spectrum, say 60MHz, must be unlicensed for use in the rural areas. It may not be out of place to mention that the USA has further mandated the use of this spectrum on a shared basis for Disaster Management agencies at times of disaster. All this therefore has the potential to catapult the broadband internet usage at a pace that will allow India to become a global leader in rural broadband penetration. Government should therefore enunciate a policy to open up and unlicense say 60MHz from the said UHF band to extend the "Digital India" programme to the rural.

Q10. What can the private sector do to reduce delivery costs? Please provide specific examples.

A10. The only seem less way to reduce delivery costs is by increasing competitive avenues.

Q11. What are the major issues in obtaining right of way for laying optical fibre? What are the applicable charges/ constraints imposed by various bodies who grant permission of right of way? In your opinion what is the feasible solution?

A11. There has to be a **single window approach for securing permission for ROW defining clear responsibilities of the authority in legal terms. For this, necessary legislation must be made.**

Q12. Should the Government consider framing guidelines to mandate compulsory deployment of duct space for fibre/ telecommunications cables and space for telecommunication towers in all major physical infrastructure construction projects such as building or upgrading highways, inner-city metros, railways or sewer networks?

A12. Yes. This should be made part of overall town planning guidelines.

Q13. What are the impediments to the provision of Broadband by Cable operators? Please suggest measures (including policy changes) to be taken for promoting broadband through the cable network.

A13. The major impediment to the provision of Broadband by Cable Operators is that the set-top-boxes deployed by them, being proprietary, are not able to deliver Broadband Internet either from their own offering by using bi-directional amplifiers, and on the other hand, or broadband offered by other operators of customer's choice. Policy change suggested is to mandate Open Set-top-box (STB) which can access broadband Internet from any Service Provider – landline, 3G or 4G operator, or for that matter, from that of the cable operator himself, with options to connect through LAN or WAN connectors. Going a step further, the same STB should be mandated to work with any DTH operator for TV programmes. **Mandate for such customer choices will pave the way for a truly Digital India.**

Q14. What measures are required to reduce the cost and create a proper eco system for deployment of FTTH in the access network?

A14. FTTH deployment will essentially drive multimedia applications. This will require high speed data centric networks with minimal packet overheads. Hence, state-of-the-art Layer-2 networks with nodes having LAN/WAN connectivity will prove to be most economic for the purpose rather than accomplishing the same through Layer-3 networks.

Q15. Are there any regulatory issues in providing internet facility through Wi-Fi Hotspots? What are the reasons that installation of Wi-Fi hotspots has not picked up in the country? What type of business model needs to be adopted to create more Wi-Fi hotspots?

A15. A virtual WiFi network consisting of thousands of hotspots all over the country – covering every city and district – will have the capability to make the dream of "Digital India" a reality. It is from this point of view that this question assumes tremendous importance. A policy enabling such a network to grow seamlessly is of central importance.

- **Regulatory Issues in providing internet facility through Wi-Fi Hotspots:**

As per current regulations, only an ISP can resell bandwidth to consumers. The ISP has to operate within the scope of his license – Category A (Country-wide) or Category B (within a State). Now if any person (or organization) other than an ISP wants to provide internet services through a Wi-Fi hotspot, he has to do one of two things: (a) Become a franchisee of the ISP or (b) Acquire an ISP license. **Both these options do not address the problem of how the hot-spot franchisee will get Internet backhauled to his hotspot**, as in most cases the ISP has no presence in the location of the proposed hot-spot and it turns out that it is not feasible to provide a copper or fiber drop either. The entrepreneurial WiFi Hot-spot provider therefore remains constrained thus, thereby resulting in poor pickup of WiFi Hot-spots in the country.

- **Business model to create more hot-spots:**

It must be recognized that if **every other citizen**, who aspires to efficiently carry out his or her business, whether large or small, by using the medium of Internet, is empowered to become a successful Hotspot provider, the aggregate outcome at the national level can have tremendous impact on the GDP. **The government should therefore put in place a popular policy that will make it easy for the franchisees to do business.**

The following suggestions are offered.

(A) A suitable wireless spectrum band capable of carrying broadband with minimal fade effects be earmarked for broadband backhaul purposes. Since the propagation requirements in an urban area is quite different than those in a rural area, two different bands may be considered – one for urban and another for rural. Typically, spectrum in the range of 5 GHz and above with appropriate power emission is suitable to cover line of sight distances of up to say 3 kms might be adequate in urban areas, whereas spectrum in the range of 400MHz to 700MHz in the UHF band with sufficiently high power emission would be suitable to cover line of sight distances of up to say 30 kms might be adequate in rural areas. A single frequency slot of MHz using OFDM technology can deliver bit rates that will support voice, video and data applications adequately. The number of frequency slots and the licensing fee should be decided so that the franchisees are not constrained by non-availability of backhaul bandwidth and he pays for the administrative costs involved in implementing the rule based allotment procedure. Government can outsource the administration of rule based allotment to private bidders.

To draw an analogy, unlicensing TVWS is like a creating a Wi-Fi hotspot. Wi-fi is bad in delivering broadband to more than 2-5 users, while a modified TVWS solution can scale for about 30-100 users very easily.

(B) The government should permit entrepreneurs to setup hotspots without requiring a Cat A or Cat B ISP license. Instead, a special hotspot operator license can be granted at a nominal fee (say 1000/-). The hotspot operator should be free to chose his Internet backhaul (it could be any one of a) DSL home broadband connection b) one or more Mobile Broadband connections – 3G/EVDO/LTE etc. or (c) regular backhaul through licensed wireless band as mentioned in (A) above.

(C) Yet another option that can be offered to a franchisee is to permit homeowners and other individuals to share their surplus internet bandwidth (an example of Collaborative Consumption) similar to the business models of airbnb.com or zipcar.com where the homeowner can permit other people to use his wireless router for a fee (or free) so long as regulatory requirements of identity are met (pre-registered community of users). Web based WiFi sharing platforms are available globally – Reference: http://www.slideshare.net/KeyWifi

Q16. What are other spectrum bands which can be unlicensed for usage of Wi-Fi technology or any other technology for provision of broadband?

A16. The TV White spaces in multiples of 8 MHz in the UHF band from 400MHz to 700MHz remain unutilized after the advent of digital/cable TV. The coverage foot prints of this spectrum extend to over 30 kms, making it an ideal candidate for rural use. The coverage actually depends upon the power limitations. The 30km is based on the 1W power radiation. If the power is increased to about 2W then the distance might quadrapule (following the inverse square law). Use of OFDM technology can provide effective solutions for overcoming fading problems. Since 70% of India's population resides in the rural areas, with extreme poverty and hardships, it makes sense to allot unlicensed spectrum dedicated for the use of rural citizens. The USA has already taken a lead in this and the Indian model can be tweaked from the US experience.

Q17. How much spectrum will be required in the immediate future and in the long term to meet the target of broadband penetration? What initiatives are required to make available the required spectrum?

A17. In the UHF band, about 64 MHz (8 slots of 8 MHz each) can be unlicensed for the free use of the rural citizen. About the same amount of bandwidth can also be given, each on licensed basis for (i) Rural back haul application, (ii) Mobile TV application, (iii) 4G Mobile services. A total of 300 MHz band is available for all the aforesaid applications. Since spectrum is a scarce resource, it must not be wasted as it is today, and must be utilized in the most equitable manner to benefit the citizen. The legacy constraints (its historic allotment for Analog TV broadcast) have no relevance to present day technology developments and user demands, and therefore should be abandoned forthwith.

Q18. Are there any other spectrum bands apart from the ones mentioned in Chapter-2 to be identified for provision of wireless broadband services?

A18. A portion of the TV White spaces in multiples of 8 MHz in the UHF band from 400MHz to 700MHz that were utilized historically for Analog TV broadcast remain unutilized after the advent of digital/cable TV should be identified for provision of broadband services.

Q19. What are the measures required to encourage Government agencies to surrender spectrum occupied by them in IMT bands?

A19. Fair usage of spectrum is to be determined. If any government agency falls short of meeting the required criteria, it should have a mandate to relinquish the spectrum, as no entity can own or lay permanent claim to spectrum as a matter of right as spectrum is a natural resource and belongs to the citizen in-as-much-as water or air.

Q20. What should be the time frame for auctioning the spectrum in 700 MHz band?

A20. A portion of the 700MHz band to be earmarked for 4G Service provision and for Mobile TV may be auctioned in stages. Views on issue and rationale for allotting unlicensed spectrum for rural use has already been mentioned in above questions under Q2, Q9, Q16 and Q17. Also, the portion of TVWS earmarked for Backhaul application must be licensed on nominal cost basis as this will directly impact broadband proliferation and hence the GDP of the country.

Q21. Do you agree with the demand side issues discussed in Chapter 5 and Chapter 6? How these issues can be addressed? Please also indicate any other demand side issues which are not covered in the CP.

A21. Most of the demand constraints discussed In Chapter 5 and 6 can be overcome if the main suggestions given in the above CP (short listed below) are adopted.

(a) **Adoption of a balanced approach** in making best possible use of the available technologies such as OFDM, etc. and a combination of licensed and unlicensed bands defining broadband spectrum policy that provides for certain appropriate bands specific to urban and rural use respectively – **for licensed operations in (i) 4G Mobile services, (ii) backhaul applications and (iii) TV mobile broadcast, as well as (iv) a certain band for unlicensed operations exclusively for rural areas.**

(b) **Infrastructure development costs in the rural segment can be reduced considerably by exploring appropriate spectrum bands that are capable of providing coverage of at least 30 kms in typical rural stretches.** The unused and hitherto **wasted spectrum** in UHF band of 400 MHz to 750 MHz once used for analog TV broadcast (also referred to as TV white spaces in the USA), can meet this requirement in good measure. **This is the simplest way to extend broadband in rural areas at least cost thereby bridging the digital divide.**

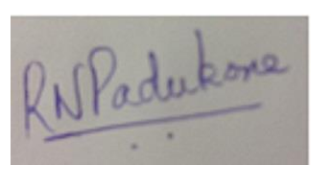
(c) Regulate content in a way that opens up the very architecture of end devices and set top boxes, to themselves act as content distributors, thereby bringing about tremendous efficiency in Internet usage. To implement this, India would have to take a lead in standardizing the content addressing scheme **and this would enable India to be virtually a global leader of Content distribution.**

(d) **Mandate for Open Set-top-box (STB)** which can access broadband Internet from any Service Provider – landline, 3G or 4G Operator with options to connect from LAN or WAN connectors, and work with any DTH operator.

(e) **Mandating a virtual WiFi network consisting of thousands of hotspots all over the country – covering every city and district –**

Q22. Please give your comments on any related matter, not covered above.

A22. Undersigned would be honored and pleased to become available for presentation/discussion on any of the subjects mentioned above.



Dated: 10-10-2014 (R.N.PADUKONE)

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Quantitative Assessment of TV White Space in India

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***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 for four zones of India (all except north) are 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 these four zones is calculated using two methods: (i) the primary (licensed) user and secondary (unlicensed) user point of view; 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 allocation scheme is presented which results in insignicant interference to the TV receivers while using the least number of TV channels for transmission across the four zones. Based on this reassignment, it is found that four TV band channels (or 32MHz) are sufficient to provide the existing UHF TV band coverage in India.**

I. Introduction

With rising demand for bandwidth, several researchers around the world have measured and studied the occupancy of spectrum 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 as low as 4.54% in Singapore [1], 6.2% in Auckland [2], 17.4% in Chicago [3] and 22.57% in Barcelona [4]. Among all the unutilized portions of the frequency spectrum, white spaces in the Ultra High Frequency (UHF) Television (TV) bands have been of particular interest owing to the superior propagation characteristics as compared to the higher frequency bands.

Loosely speaking, 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]. The estimation of TV white space in the UHF band, based on spectrum allocation and TV transmitter parameters, is presented in this work.

This work has been supported by the Ford Foundation.

The main contributions of this paper are the following:

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 in the literature, namely pollution and protection viewpoints [5], and the technical specifications of the Federal Communications Commission [10]. It is found that UHF TV band spectrum is heavily underutilized in India.
2) Motivated by underutilization of UHF TV band spectrum, a spatial reuse based channel allocation algorithm has been proposed for the existing Indian TV transmitters operating in the 470-590 MHz band. The algorithm uses the least number of TV channels while ensuring no (significant) interference between transmitters operating in the same channel. It is observed that at least 70% UHF TV band channels can be freed by this approach.

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 the amount of TV white spaces in India. Besides, based on above results, the TV band in India is underutilized and this situation is quite different than in the developed countries. The optimal mechanism(s) for the use of TV white spaces in India can be *different* and it should be studied by further research.

Organization: The TV white space scenario and the related work on quantitative analysis in a few other countries is briefly described in Sec. II. Sec. III describes the current Indian usage scenario of the UHF TV Bands. Sec. IV presents the methodology and assumptions used in calculating the white space availability in India. Sec. V presents the results of our work, and compares the TV white space availability in India with that of other countries. In Sec. VI, we propose a frequency allocation scheme to the TV transmitters in India so as to ensure minimum number of channel usage in the country. Concluding remarks and directions for future work are discussed in Sec. VII.

II. TV White Space in other countries

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 actual availability of TV white spaces varies both with location and time, operators of secondary services are interested in the amount of available white space. The available TV white space depends on regulations such as the protection margin to the primary user, maximum height above average terrain (HAAT), transmission power of secondary user, and the separation distance.

As per FCC, a band can declared as unutilized if no primary signal is detected above a threshold of -114dBm [10]. 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 [11]. 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 [12], 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 [12]). 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 1415 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 8MHz each), and the remaining 373 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] Out of 373 transmitters operating in the 470-590 MHz UHF band (Channel No. 21-35), Doordarshan has provided data of 254 towers operating in the West, East, South and the North East zone. The TV transmitter information for the North zone is yet to be provided by Doordarshan.

Comprehensive field strength measurements in India suggest that Hata model is fairly accurate for propagation modeling [14], [13]. 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]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.

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

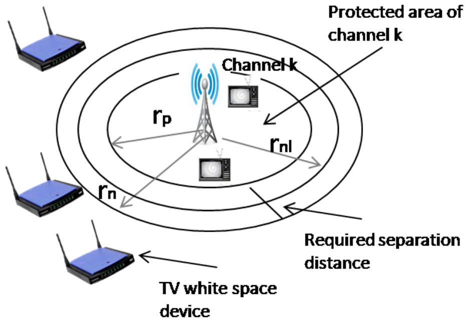

Fig. 1. Protection radius, separation distance and the no-talk radius

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 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 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 [10]) 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,

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

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.

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. Doordarshan informed us that 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

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

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], [10]. 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 [15],

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

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 the four zones. 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 the west, east, south and north-east zone 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.

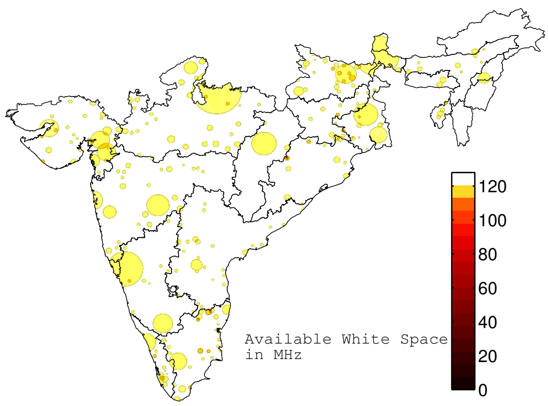

Fig. 2. TV White Space availability using Pollution viewpoint $\gamma = 15dB$

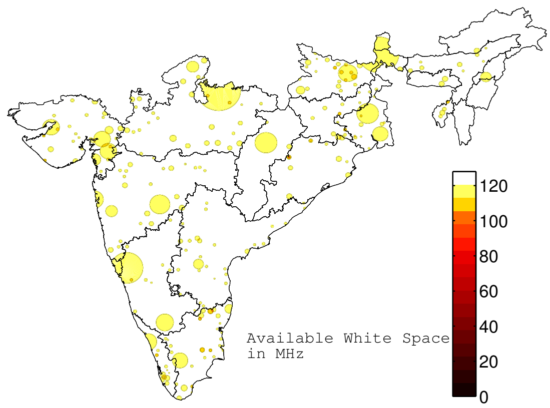

Fig. 3. TV White Space availability using Protection viewpoint $\Delta = 1dB$

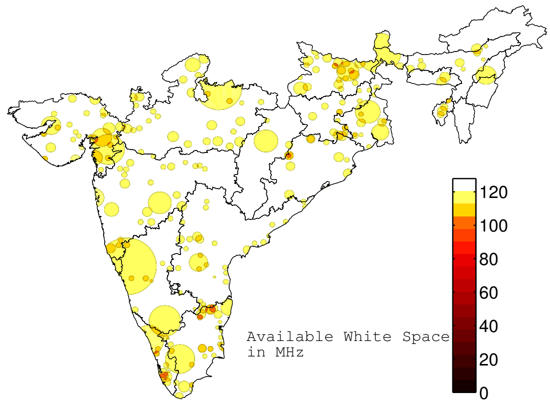

Fig. 4. TV White Space availability using FCC rule

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

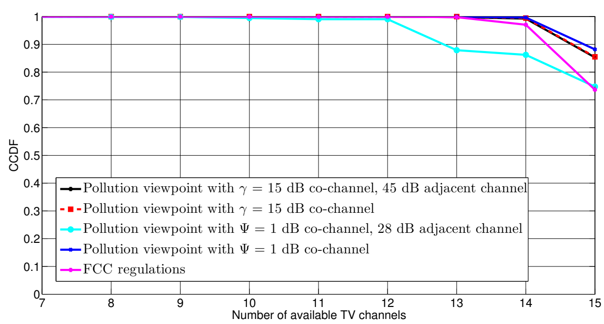

Fig. 5. Complementary cumulative distribution of the available number of channels per area as white space

viewpoint with γ = 15dB, 85.29% of the area in India has all the 15 channels available as white space, while in 100% of the area, 12 or more channels are available as white space. Similar results are obtained using the protection viewpoint with Ψ =

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

Method	Parameters	West zone	East zone	South zone	North east zone	India
Pollution Viewpoint	Main channel γ = 5 dB	14.0047	14.2313	14.4745	14.8464	14.2130
	Main channel γ = 5 dB, Adjacent channel γ = 45 dB	13.9957	14.2223	14.4693	14.8443	14.2054
	Main channel γ = 10 dB	14.6896	14.6295	14.7374	14.9213	14.6856
	Main channel γ = 10 dB, Adjacent channel γ = 45 dB	14.6835	14.6205	14.7322	14.9192	14.6792
	Main channel γ = 15 dB	14.8545	14.8214	14.8683	14.9599	14.8496
	Main channel γ = 15 dB, Adjacent channel γ = 45 dB	14.8485	14.8123	14.8630	14.9578	14.8432
Protection Viewpoint	Main channel Ψ = 1 dB	14.8830	14.8549	14.8917	14.9673	14.8782
	Main channel Ψ = 1 dB, Adjacent channel Ψ = 28 dB	14.5372	14.4558	14.3666	14.6939	14.4616
	Main channel Ψ = 0.1 dB	14.8664	14.8351	14.8782	14.9630	14.8616
	Main channel Ψ = 0.1 dB, Adjacent channel Ψ = 27.1 dB	14.4720	14.8429	14.5745	14.8661	14.4792
FCC regulations	Main channel E_{r_b} = 41 dBu	14.7762	14.6795	14.6510	14.8844	14.7050

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%	36.69%
	Main channel γ = 5 dB, adjacent channel γ = 45 dB	100%	100%	36.43%
	Main channel γ = 10 dB	100%	100%	71.61%
	Main channel γ = 10 dB, adjacent channel γ = 45 dB	100%	100%	71.39%
	Main channel γ = 15 dB	100%	100%	85.51
	Main channel γ = 15 dB, adjacent channel γ = 45 dB	100%	100%	85.29%
Protection viewpoint	Main channel Ψ = 1 dB	100%	100%	88.19%
	Main channel Ψ = 1 dB, adjacent channel Ψ = 28 dB	99.88%	99.04%	74.75%
	Main channel Ψ = 0.1 dB	100%	100%	86.62%
	Main channel Ψ = 0.1 dB, Adjacent channel Ψ = 27.1 dB	99.99%	99.57%	73.69%
FCC Regulations	Main channel E_{r_b} =41 dBu	100%	100%	73.66%

1 dB which shows that in 74.75% of the area in India, all the 15 channels are available for TV white space secondary operations, and in 99.47% of the area, 10 or more channels are available as white space. With the FCC regulations, which are considered to be conservative (see [5]), 73.66% 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 the four zones 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 each of the four zones.
2) Available TV white space is the maxium 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 254 Doordarshan TV transmitters in the four zones illustrated in Fig. 6 operating in the 470-590MHz. Currently, in these 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 254 transmitters, only 24 transmitters in the four zones 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 for four zones are given in Fig. 7. Under this channel allocation scheme, the maximum number of distinct TV channels required in the entire zone is four, which is much smaller than the fourteen channels currently used in India. To avoid adjacent channel interference, the overlapping channels

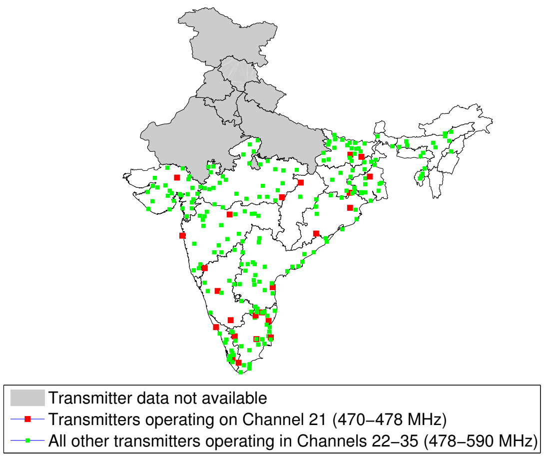

Fig. 6. TV Transmitters operating in UHF Band-IV (470-590MHz)

for *All transmitters in the four zones;*
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

must be non-adjacent.

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 36.43% areas in the four zones 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 [10]. 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 maximize unused spectrum. It was observed that four TV channels (or 32MHz) are sufficient to provide the existing UHF TV band coverage in India.

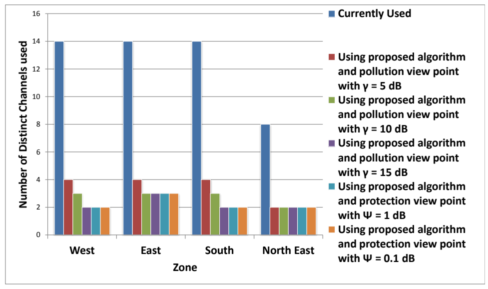

Fig. 7. Number of channels required in currently and after using the proposed algorithm

In the future, we plan to obtain and include the missing north zone data in our work. We also 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.

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