Journal of Advanced Computer Applications *ISSN No.: XXXX-XXXX*
vol-01, issue-01, December, 2024 *Pages 129-139*

JOURNAL OF ADVANCED COMPUTER APPLICATIONS

ISSN: XXXX-XXXX (Online)
Vol: 01 **Issue:** 01
Contents available at: https://www.swamivivekanandauniversity.ac.in/jaca/

Global TVWS Scenario

Pradipta Maity[1] *

[1] *Department of Electronics and Communication Engineering, Swami Vivekananda University, Barrackpore-700121, WB, INDIA, Email ID: pradiptam@svu.ac.in**

ABSTRACT
This paper reviews the quantitative assessment of outdoor and altitude-considered indoor television white space (TVWS) from global and Indian perspectives based on various aspects and equipment set-ups through many research explorations. Current study shows a rapid increase in internet use, which increases the spectrum demand to maintain high-speed data for mobile subscribers. As digital switchover (DSO) fails to reach the spectrum de-mand, global research, including from India, explores that TV service providers have a large amount of vacant spectrum to compensate for the excess data traffic by unlicensed dynamic spectrum access (DSA) through cognitive radio network (CRN) for the band limited mobile services providers. Global exploration shows that 70%-80% of the TV channels are free in the majority of countries as well as in India. Research shows that most of the data traffic is generated indoors. Thus, indoor exploration of TVWS in the spatial domain is necessary. As per the indoor TVWS assessment of our previous research, it is found that 7%-10% of TVWS volume could be explored due to the losses for the indoor obstacles from an active TV channel indoors. It could compensate for indoor, high-speed data traffic during busy hours. More indoor TVWS exploration of high-rise office buildings could create an indoor TVWS data-base platform for cognitive functionalities to maintain high-speed mobile da-ta. Federal Communication Commission (FCC) proposes a global regulation standard for the opportunity to utilize unused ultra-high frequency (UHF) and very high frequency (VHF) TV channels. It opens new scopes for cognitive functionalities indoors.

Keyword: TV White Space, Cognitive Radio, Dynamic Spectrum Access.

I. INTRODUCTION

In telecommunication, white space (WS) means unused frequency allocated to the broadcasting services [1]. Television WS (TVWS) indicates the unused portions of the spectrum in the TV bands, such as unused channels, guard bands between the channels, and free channels generated after digital switchover (DSO) in very-high frequency (VHF) and ultra-high frequency (UHF) bands. In spectrum-inefficient analog TV broadcasting, empty

* Authors for Correspondence

guard bands added to each channel to reduce interference. Digital signals does not face this type of problem. Therefore, they can be packed closer together to get higher mobility and throughput. As a result, the requirement of spectrum in digital television networks becomes less. There are several advantages of using VHF and UHF spectrum for TV broadcasts [2]. Radio signals have requiring fewer base stations for coverage, a long-range, resulting in cheaper networks. It reduces capital expenditure on network equipment and maintenance, and operational costs. A long signal range is beneficial to provide coverage in rural areas. TV broadcasting frequencies (54-806 MHz) have a long wavelength to achieve better speed.

Wi-fi data rate is 160-300 megabits/ second (Mbps), whereas WS can send data at 400-800 Mbps rate. TVWS radio signals have excellent in-building penetration capability, providing deep in-building coverage and allowing ubiquitous coverage. Non-line-of-sight performance offers penetrability into obstacles, like – buildings, trees, and rugged terrain.

TVWS are unrestricted to unlicensed users and the regulators are considering al- lowing TVWS devices to operate on the TV. The WS provided that they do not cause interference to the primary spectrum users. Unused spectrum significantly reduces the costs of wireless network operation. WS is expected to be available globally as TV bands are harmonized worldwide. Global marketplace offers scale for network equipment and devices on the economic prospect. It will spur common standards and technologies while allowing manufacturers to mass-produce equipment, driving down unit costs. A massive empty spectrum is available as TVWS. A survey report shows that approximately 100 MHz spectrum is available in most of US and UK locations [1]. Economically developing countries, like - India and South Africa have a more vacant spectrum due to less utilization of TV channels. Unlicensed TV band users use a wire- less microphone and Bluetooth-like TVWS devices to communicate on the free frequency channels [3]. Therefore, avoiding interference between these devices using the same spectrum is essential. TVWS devices must determine the specific time and location-based frequency bands. A geolocation database depicts a real-time view of spectrum usage in the TV band by particular time and location to communicate over the available frequencies by TVWS devices before cognitive radio operation. TVWS base stations act as intermediators in this process and estimate the frequencies used by terminal devices within its control. Primary devices coordinate to ignore interference caused by devices within the TVWS network. As per the European Commission (ECC) estimation, 7.1 billion phones, tablets and other mobile devices are expected to be connected to the internet globally [4, 5].

With increase in automation, the amount of wireless-enabled devices is expected to explode also. Spectrum sharing is essential to alleviate the current network and predicted network load, and TVWS technology is part of the solution. Total TV spectrum is divided into a few channels with fixed bandwidth. During broadcasting, only a few channels are utilized. Most developed countries have started the DSO process for converting the TV station from analog to digital in developing digital broadcasting technology. As the spectrum efficiency of the digital channels are efficient than the analog channels, some spectrum occupied by analog channels will become vacant during this DSO. There will be many TV channels not used for digital TV (DTV) broadcasting in a given geographic area to avoid co-channel or adjacent channel interference between TV stations also. Due to the interference planning rules, some spectrum will become vacant for low-power device operation also. The mobile service providers can utilize this TVWS by providing cognitive access for their services. Thus, an assessment of TVWS is necessary to make a reference database platform in frequency, time and spatial domain for unlicensed spectrum access through cognitive radio network (CRN).

The remaining paper arrangements are given as follows – Section II, Global TVWS Scenario; Section III, TVWS Scenario in India; and Section IV, Conclusion.

II. GLOBAL TVWS SCENARIO

Cisco Visual Networking Index: Forecast Update, 2017–2022 Global Mobile Data Traffic reports major global mobile data traffic growth trends and projections over the last decade [6]. It states a survey assessment of rapid growth in mobile data traffic, mainly in global systems for mobile (GSM) and industrial-scientific-medical (ISM) bands, due to the increasing uses of mobile smart devices in the past few years. The assessment shows that smart devices generate ten times more data traffic than non- smart devices. As per the report, cellular networks' monthly global mobile data traffic will be 77 exabytes, and annual traffic will reach about one zettabyte by 2022 due to advancement from second generation (2G) to fifth generation (5G). The 5G connectivity with a high bandwidth of 100 Mbps and ultra-low latency of one millisecond is expected to drive high traffic volume. Study shows that much mobile data activity occurs indoors, mainly within the office and at home. A robust proportion of generated traffic through mobile and portable devices is offloaded from the mobile networks onto the fixed networks for users with fixed broadband and wi-fi access points at home or for users served by operator-owned femtocells and pico-cells. Offload pertains to the traffic from dual-mode devices over wi-fi and small-cell networks in this study. Offloading occurs at the user or device level when one switches from a cellular connection to small-cell access or wi-fi. Our mobile offload projections include traffic from both residential wi-fi networks and public hotspots. Mobile offload increases from 54% or 13.4 exabytes/month in 2017 to 59%, approximately 111.4 exabytes/month by 2022. Globally, total public wi-fi hotspots, including home spots, will grow four-fold from 2017 to 2022, from 124 million in 2017 to 549 million by 2022. Real wi-fi home spots will grow from 115 million in 2017 to 532 million by 2022. Also, the past assessment of the future of the Internet of Things (IoT) shows the rapid growth in internet utilization increases the demand for a high-speed data rate [7]. Designing a network with sufficient bandwidth support is challenging to facilitate flawless connectivity of this enormous data traffic. Massive data traffic faces the problem of insufficiency in band- width. The digital switchover (DSO) technique supports the increasing bandwidth demand worldwide by releasing a small bandwidth of each frequency channel, but it fails to compete with the sharply increasing bandwidth demand [8].

The studies from [9][10] show that cognition of excess data traffic to other vacant or partially vacant bands could compensate for the overloaded data traffic. Dynamic Spectrum Access (DSA) could reach this task on the vacant frequency channels or WSs through the cognitive radio network (CRN) as an unlicensed secondary user (SU). CR mainly consists of a cognitive engine (CE), contains toolboxes and algorithms for radio environment sensing, reasoning, machine learning, and decision-making with configu rable radio platforms, such as - Software Defined Radio (SDR). SDR follows the instructions of CE. Worldwide, several explorations by different telecom regulatory authorities reveal that most vacant and partially vacant bands belong to the TV broadcasting authorities. On the other hand, the worldwide DSO from analog TV transmission to the more spectrally efficient Digital Video Broadcasting – Terrestrial (DVB-T) has created new vacant frequency channels, i.e. buffer guard bands that were earlier used to protect against broadcast interference. Ultra-high frequency (UHF) and very high frequency (VHF) bands have excellent penetrating and propagation capabilities, so these bands are used for TV broadcasting globally. Unutilized and underutilized spec trums of TV channels are collectively called the TVWS. They provide promising scope for better coverage at lower transmission power and higher throughput in applications such as indoor local area network (LAN), rural broadband and wireless sensor networks (WSNs), long-time evaluation (LTE), Smart metering, and mobile-to-mobile (M2M) communication [11]. The completely empty channels are called TVWS, and the partially empty channels are called TV grey space (TVGS) [12]. Research shows that TVWS and TVGS could be the best compensators for the excess data traffic of the SUs through CRNs by DSA due to their better penetration power and availability in bulk amounts globally [13]. In November 2008, the Federal Communication Commission (FCC) gave the first offering to the wireless world - the opportunity to use the empty TV bands in the VHF and UHF bands, with several conditions and limitations [5]. Regulations standards have been proposed to utilize TVWS through CRNs [14]. The standardization summary is given in Table 1.

Table I Standardization for TVWS

Standardization	Main features
802.11af	802.11af is the enabling technology in TVWSs for wireless local area net- work (WLAN) systems. The key strength is the utilization of 802.11 standards user experience. The potential challenge is the uncertainty of the performance of standard GHz-band WLAN physical (PHY) layer design in the TV bands.
802.22	802.22 specifies enabling technologies in TVWSs for WRAN system. Themain strength is the incorporation of multiple CR functionalities.

	The potential challenge is implementation complexity and cost-effectiveness.
802.15.4m	802.15.4m specifies enabling technologies in TVWS for Low-Rate Wireless Personal Area Network (LR-WPAN) systems. The main strength is the utilization of 802.15.4 user experience in the smart utility *network* (SUN) sys- tem. The potential challenge is the coexistence issue for multi-PHY-layer design.
802.19.1	802.19.1 is the coexistence framework for dissimilar systems in 802 standards. Main strength is the first intersystem coexistence standardization effortin TVWSs for Institute of Electrical and Electronics Engineers (IEEE) 802. A challenge is getting support and compatibility from participating system.
1900.7	1900.7 specifies enabling technologies in TVWS communications. The main strength is the utilization of 1900 standards user experience in DSA.

Different opportunities and applications of TVWS as SU has been discussed in [15, 16], [17]. Proposal on experimental verification of indoor WS opportunity prediction model has been discussed and verified in laboratory and real-world environments [18]. The evaluation suggests opportunistic low-power indoor spectrum usage via TVWS. Short-range WS utilization in broadcast systems considering interference for indoor home scenarios [19]. As per the assessment of different countries, it is exploredthat 100% of TV channels are vacant in 57% of countries, increasing the wireless connectivity demands. Like other countries, the WS is relatively more rural than urban, and75% of our areas have all 15 channels in 470 to 590 MHz free, providing a bandwidthof about 105 MHz [20]. The above study on the global indoor TVWS scenario shows a larger scope for more WS availability through indoor 3D TV band RSS dataset exploration through different estimation techniques.

III. TVWS SCENARIO IN INDIA

The government of India has been published the National Frequency Allocation Plan (NFAP-2018) [21]. It shows that DSO of the TV spectrum on frequency channels 470- 806 MHz has started allowing fixed-mobile broadcasting services on a primary basis. According to the proposed plan for the year 2018, the Telecom Regulatory Authority of India (TRAI) [22] and the Department of Telecommunications (DoT) had proposed to allocate some portion of the TV spectrum for International Mobile Telecommunica tions-Advanced (IMT-A) services after the completion of DSO process for terrestrial TV transmission [23][24]. Researchers have proposed to use wi-fi-like networks for broadband services backhauled by fibre-optic networks all over India [25][26]. The Government of India has initiated the Digital India program, collaborating with different institutions to provide e-agriculture, e-health, e-animal husbandry, e-education, and e-governance services in rural areas through broadband connectivity [23]. Researchers have started to quantify geolocation assessment of TVWS areas all over India. Assess ment shows that TVWS evaluated from the VHF band (174-230 MHz) is 96.45% and 92.78% for the UHF band (470-806 MHz) for suburban locations and 100% in rural areas [27][25]. Researchers have quantitatively surveyed FCC rules, protection, and pollution viewpoints. As per FCC regulations, 73.66% of the area in India has all 15 channels available and 12 or more channels available in 100% of the area for TVWS operations. From a protection viewpoint, the WS area is 74.75% in India. All 15 chan- nels are available for secondary users, and ten or more channels are available as WS in 99.47% of the area. 85.29% of the area in India has all the 15 channels available as TVWS, whereas 100% of the area, 12 or more channels are available from a pollution point of view. Out of the 15 UHF TV channels (470-590 MHz), the average number of TV channels available for secondary usage is about 14 (112MHz) in four zones. The available TVWS is the maximum in the North East, where 18 transmitters operate in the UHF band. By using the adjacent channel constraint, the available WS decreases. It has been observed that 12 out of the 15 channels (80%) are available as TVWS in India. Based on conservative parameters, at least 36.43% of areas in the four zones of all 15 channels are free, or 100% of the TV band spectrum is vacant. The maximum available TVWS is more than 100 MHz in many areas [25].

Survey report of the Government of India project "Spectrum-Aware Rural Connec tivity (SPARC)", funded by the Department of Electronics and Information Technology (DeitY), shows a huge availability of TVWS all over India [26]. Project Meghdoot has been conducted for wi-fi connectivity in rural India [28]. The discussion has been done on exploring the femtocell WS for short-distance wireless networks strictly without interfering with licensed DTV transmissions [23]. More field measurements have been done, and the complete scenario of TVWS could be getable after completion of DSO [27], [29], [30]. IEEE 802.11af standard-based SU transmission power, considering the shadow fading effects and interference limit, has been discussed and compared with the Monte Carlo Simulation results to explore the area of TVWS [31]. The Ford Foundation-supported research has proposed an algorithm for channel allocation and an alternate spectrum sharing mechanism termed Licensed Shared Access (LSA) for facilitating the rural broadband service using TVWS nodes based on Protocol to Access WS (PAWS). The PAWS protocol defines the Application Program Interfaces (APIs) required at the TVWS database and messages interchanged between the PAWS controller device and the database of India [32]. Open source PAWS and UHF TVWS database implementation for India and a new architecture of multi-hop mesh network for data- base-assisted TVWS in India have been proposed. The transmission power of a TV tower operating on any particular channel sets the tower's coverage area and the TVWS areas. The researchers have discussed the regulatory framework of radio frequency (RF) signals in India based on the report of the International Telecommunication Union (ITU) and Wireless Planning Coordination (WPC) [33]. European Telecommunications Standards Institute (ETSI) Reconfigurable Radio System (RRS) technical committee reports on the use cases for mid/long and short-range wireless access based on user mobility and opportunistic spectrum access to TVWS by cellular systems in the absence of primary user and ad-hoc networking over WS frequency channel. Researchers [30] has proposed spatial and temporal variation supporting the stochastic duty cycle model based on the TVWS database for CR poten tial measurement for different wireless networks for specific wireless service. Stochastic Duty Cycle model based on CR considering the choice of suitable wireless services to explore the TVWS for wireless broadband backhauled by optical fiber with the sup- port of CR operation in rural India. The power spectrum density (PSD) graph has been analyzed for the spectrum occupancy [27, 29].

The wireless broadband network architecture model on TVWS for rural areas and TVWS capacity analysis based on the current spectrum allocation band plan for dynamic spectrum sharing [24]. A quantitative assessment of TVWSs for CRN in India has been performed [23]. Protection, pollution, and FCC regulation-based quantitative evaluation show that 80% of the channels are available as TVWS without any adjacent channel interference in India [25]. It presents a middle-mile multi-hop mesh network operating in the UHF TV band to provide rural broadband coverage between optical fibre-PoP at designated points and broadband users [34]. For WS detection and spectrum characterization, two metrics: "power level cumulative distribution" and "maxi- mum contiguous bandwidth available," have been contrasted in the project "SPARC: Spectrum-Aware Rural Connectivity", funded by the Department of Electronics and Information Technology (DeitY), Government of India [26]. An application has been developed that overlays the geographical area with a spectrum databases. It defines "non-interference" energy thresholds, allowing an SU to point out at a location on a map and generates a spectrum graph showing the available WSs. It would provide the permissible importance’s for maximum "secondary transmission signal strength" for that region by enabling a WSN. A rural broadband plan in India, based on zero/low/high mobility and uncoordinated/coordinated networks, has proposed an approach to avoid interference from the TV receiver's PU to the SU to restrict the power of SU. The per formance of the proposed power estimation method for SU was in alignment with Monte Carlo Simulation; interference and shadow fading were of tolerance limit [23]. In [35], we have presented the results and analyses of the robust Received Signal Strength Indicator (RSSI) of two UHF TV channels broadcasted from Doordarshan Kendra, Dhanbad (DDK), India. The RSSI measurement of those channels were done for 24 hours on each floor of the New Academic Complex building at IIT(ISM) Dhanbad, India. The data analysis presents the average RSS on each floor and signal attenuation due to the influence of those two channels' doors, windows, walls, and other ap appliances on each floor. The opportunities to utilize the TVWS for indoor small cell deployment for CRN and the prospect of designing a REM have been discussed and analyzed. The paper presents the comparison of the pathloss models – Hata, Perez-Vega Zamanillo (PVZ) with practical values of propagation pathloss of those two TV chan nels. An overall analysis of the TVWS scenario in India indicates the lack of indoor WSs in India. Researchers could get extra WSs for indoor communications and DSA through different exploration techniques through CRNs. Our previous works in [36]–[38] have discussed the exploration of TVWS and TVGS indoors in frequency, time and spatial domain. Frequency domain exploration shows that 87% of the TV channels are free under DDK Dhanbad, and it increases to 100% during the OFF time of the broadcasting. The spatial domain analysis shows that active TV channels become free indoors due to the losses of different indoor obstacles. Various interpolation-based analysis explores different volume of TVWSs indoors. The best-explored volume is 7.36% of the total building volume. Indoor TVWS volumes could be utilized for unlicensed secondary access operations through CRNs during high data traffic hours.

IV. CONCLUSION

This paper discusses the current scenario of wireless data traffic on the problems that arise from spectrum scarcity, global exploration of TVWS, and quantitative assessment of TVWS in India from different perspectives. Analysis shows that majority of the countries have most of its TV channel vacant. It could give the opportunity to the unlicensed spectrum channels to use the TVWSs to unleash the excess data traffic through CRNs to maintain the high data rate. Mostly wireless data traffic generates in indoor, thus, altitude considered indoor TVWS exploration has been discussed for the first time. TVWS availability in time-frequency-spatial domain has been explored. From the sur- vey on quantitative assessment of TVWS from other measurements in India, it is seen that 80% of channels are always vacant, 100% vacant during channel OFF time and active TV channels becomes vacant due to the losses for indoor obstacles. The regulations standards to utilize TVWS through CRNs proposed by FCC have been discussed. In future, more indoor exploration in necessary to access the indoor TVWS in spatial domain for more active TV channels. Opportunities, like - femtocell wireless broad- band in TVWS, LTE extension, public safety applications that will come after the completion of the DSO and TVWS exploration.

REFERENCE

1. A. K. Mishra, D. L. Johnson, and E. Challenges, White Space Communication: Advances, Develop-ments and Engineering Challenges. Switzerland: Springer International Publishing, 2015.
2. R. A. Saeed and S. J. Shellhammer, TV White Space Spectrum Technologies. Florida, USA:

CRC Press, 2016.
3. G. Coulson and D. Ferrari, e-Infrastructure and e-Services for Developing Countries, vol.
4. 208. Cham: Springer International Publishing, 2018.
5. A. Roy and H. S. Dhillon, 6G Mobile Wireless Networks. Cham: Springer International Publishing, 2021.
6. S. W. Oh, Y. Ma, E. Peh, and M.-H. Tao, TV White Space. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2016.
7. Cisco, "Cisco visual networking index: Global Mobile Data Traffic Forecast Update, 2017-2022," 2019. [Online].
8. D. Evans, "The Internet of Things How the Next Evolution of the Internet Is Changing Every-thing," 2011.
9. D. Mijatovic, "Guide to the Digital Switchover," Vienna, 2010.
10. I. F. Akyildiz, R. Agusti, F. Casadevall, and M. L. Benítez, "FARAMIR D2.1," 2010. [Online].
11. P. Setoodeh and S. Haykin, Fundamentals of Cognitive Radio. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2017.
12. F. Akhtar, M. H. Rehmani, and M. Reisslein, "White space: Definitional perspectives and their role in exploiting spectrum opportunities," Telecomm. Policy, vol.40, no.4, pp. 319–331, Apr.2016.
13. S. W. Oh, Y. Ma, M. Tao, and E. Peh, "Introduction to Cognitive Radio and Television White Space," in TV White Space: The First Step Towards Better Utilization of Frequency Spectrum, 2016, pp. 1–22.
14. S. LEI and L. Shi, "Availability Assessment for Secondary Access in TV White Space," KTH Royal Institute of Technology, Communication Systems, CoS, School of Information and Communication Technology (ICT), KTH, 2012. [Online].
15. R. A. Saeed and S. J. Shellhammer, TV White Space Spectrum Technologies. Florida, USA: CRC Press, 2016.
16. K. Ruttik, "Secondary spectrum usage in TV white space," Aalto University, 2011.
17. K. Naidu et al., White Space Communication. Cham: Springer International Publishing, 2015.
18. N. B. Carvalho and A. Cidronali, White Space Communication Technologies, 1st ed. London: Cam-bridge University Press, 2005.
19. E. Obregon, L. Shi, J. Ferrer, and J. Zander, "Experimental verification of indoor TV White Space opportunity prediction model," in Proceedings of the 5th International ICST Conference on Cognitive Radio Oriented Wireless Networks and Communications, 2010, pp. 1–5.
20. E. O. Gamarra and J. Zander, "Short Range White Space Utilization in Broadcast Systems for Indoor Environments," in 2010 IEEE Symposium on New Frontiers in Dynamic Spectrum (DySPAN), Apr. 2010, pp. 1–6.
21. A. Maheshwari, A. Gopalakrishnan, H. A, N. Mangla, P. Bhagavatula, and R. Goyat, "TELEVISION WHITE SPACES–GLOBAL DEVELOPMENTS AND REGULATORY," 2013.

22. NFAP, "National Frequency Allocation Plan-2018," New Delhi, India, 2018.
23. TRAI, Telecom Regulatory Authority of India, no. 9. 2007, pp. 1–99.
24. M. Deshmukh, K. P. Patil, S. Kharote, A. Jadhav, and S. Maskar, "Quantitative assessment of TV white spaces for cognitive radio networks in India," in 2014 International Conference on Contemporary Computing and Informatics (IC3I), Nov. 2014, pp. 619–624.
25. M. Deshmukhl et al., "Wireless broadband network on TVWS for rural areas: An Indian perspective," in International Symposium on Wireless Personal Multimedia Communications, WPMC, 2013, vol. 499.
26. G. Naik, S. Singhal, A. Kumar, and A. Karandikar, "Quantitative assessment of TV white space in India," in 2014 Twentieth National Conference on Communications (NCC), Feb. 2014, pp. 1–6.
27. P. Kumar et al., "White space detection and spectrum characterization in urban and rural India," in 2013 IEEE 14th International Symposium on "A World of Wireless, Mobile and Multimedia Networks" (WoWMoM), Jun. 2013, pp. 1–6.
28. K. Patil, K. E. Skouby, and R. Prasad, "Spectrum measurement and analysis of TV band support of Cognitive Radio operation in India," in Wireless VITAE 2013, Jun. 2013, no. 4, pp. 1–5.
29. Anand Murali, "Pruthvi, a chip, can connect India's rural population to the internet - The Economic Times." ET Bureau, 2015.
30. K. Patil et al., "Cognitive Access to TVWS in India : TV Spectrum Occupancy and Wireless Broadband for Rural Areas," in 2013 16th International Symposium on Wireless Personal Multimedia Communi-cations (WPMC), 2013.
31. K. Patil, K. E. Skouby, and R. Prasad, "Stochastic duty cycle model based on measurement for Cogni-tive Radio," in International Symposium on Wireless Personal Multimedia Communications, WPMC, 2012, pp. 128–132.
32. P.Sharma and G.Rammurthy, "Rural broadband plan in India: A TVWS scenario," in 2014 IEEE 2nd International Symposium on Telecommunication Technologies (ISTT), Nov.2014, pp. 98–103.
33. S. Ghosh, G. Naik, A. Kumar, and A. Karandikar, "OpenPAWS: An open source PAWS and UHF TV White Space database implementation for India," in 2015 Twenty First National Conference on Communications (NCC), Feb. 2015, pp. 1–6.
34. T. Satish et al., "TVWS opportunities and regulatory aspects in India," in 2011 the 14th International Symposium on Wireless Personal Multimedia Communications: Communications, Networking and Ap-plications for the Internet of Things, WPMC'11, 2011.
35. A. Kumar, R. Kumar, P. Rathod, and A. Karandikar, "How much TV UHF band spectrum is suffi-cient for rural broadband