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A review paper on broadband connectivity in rural India through TV white space

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ABSTRACT

In India, there has been an immense growth in the number of telephone and broadband subscribers in the last few years. In next-generation wireless technology that converged voice and data applications will offer rural broadband connectivity for proper boost in Information and Communication Technology(ICT) to take part in all the areas of human life such as education, health, science, financial markets, security and civil protection, media, entertainment, and business development etc. Unused spectrum in the television band (so-called TV white space) has the potential to provide a new spectrum for accessing information and communication services in developing countries. "White spaces" in the UHF (Ultra High Frequency) bands that have traditionally been used for television broadcasting but the opening of TV white space (TVWS) bands for cognitive access is one of the first tangible steps to solve the problem of Spectrum scarcity in current wireless networks. One of the major hindrance to providing broadband connectivity in a semi-urban area and rural India is the lack of robust and affordable backhaul. Fiber connectivity in the terms of backhaul is being planned or provided by Government of India would reach only till rural offices named as Gram Panchayat in the Indian rural areas. In this elucidation, I articulate how TV white space can address the challenge of providing broadband connectivity to a billion plus population within India. As villages can form their local Wi-Fi clusters. The problem of connecting the Wi-Fi clusters to the optical fiber points can be addressed using a TV white space-based backhaul (middle-mile) network. I also try to cover the TV White Space technology, the pertinent standards to the TVWS system, the regulatory framework and other relevant points. In the target riverine country like India, TVWS wireless connectivity model can play a vital role to develop rural community. In this paper, my objectives are to Explore, assess and propose TV white space implementation of rural broadband in India to make Digital India.

Keywords*— Cognitive radio, TVWS, Wireless networks, Wireless mesh networks, Access networks*

1. INTRODUCTION

In the past few decades, India has witnessed ever-increasing wireless telecom connectivity. This wireless communication is directly linked with desire of fast data rate and reliable connectivity. There are over 940 million wireless telecom subscribers with a teledensity of over 77, and India has become the second largest telecom market in the world. These numbers along with the advent of 3G and 4G systems would hint that wireless broadband access in India has been solved; however, the reality is far from it! The number of broadband subscribers is around 86 million, and the rural teledensity is 46 (compared to the urban teledensity of 148). However, it can be stated emphatically that the rural or affordable wireless broadband access is an unsolved problem in India. Rural India has purchasing capacity since it contributes 50% to the GDP of India, though it has only 1.5% registered broadband connections. It appears that rural broadband area is a largely untapped market with great potential. However, there are significant challenges in providing broadband access in the rural areas, including:

(i) Small Average Revenue Per User (ARPU) as a fraction of total revenue;
(ii) High capital and operation expenditure (including license fees);
(iii) Affordable backhaul which is worsened due to a very large population,
(iv) Energy cost which is exacerbated by lack of reliable power supply; and
(v) Geographic accessibility issues such as 'right of way problems'.

To alleviate the lack of broadband in rural areas, the Government of India has been working with the initiative Bharat Net (formerly National Optical Fiber Plan or NOFN)[1]. With the ongoing efforts to meet the goal of broadband connectivity in rural India, there has been a steep increase in the demand for bandwidth for communication systems and also the preferential shift from the usage of fixed wire-line technologies to mobile technologies. With the drastic increase in the demand for mobile connectivity, comes the inevitable pressure on the supply side of the resource, being the radio spectrum the necessary resource to enable wireless technologies to transmit and receive data. It has been felt worldwide to devise ways for efficiently managing the spectrum to serve the exponentially growing demands. This has led to the development of different techniques for addressing the spectrum crunch and also to optimize the use of the available spectrum.

One alternative mode of spectrum utilization is finding popularity world over is the use of TV White Spaces for communications systems. TV white spaces (TVWS) are 'segments of spectrum left unused by broadcasting, also referred to as interleaved spectrum'. The TV White spaces have outstanding propagation characteristics and hence are a huge attraction worldwide for wireless communications. Countries like US, UK, Canada & Singapore have already formulated regulations for the usage of TV White Spaces for wireless communications (fixed and mobile), and many others like Japan, Hong Kong etc. are actively considering to do the same. But the amount of TV white space present in India is very large when compared with the developed world so why not we take the advantage of the same.

2. TV WHITE SPACE AND TECHNICAL OVERVIEW

2.1 Cognitive Radio Technology

The TVWS technology-based communication system is mainly based on the Cognitive radio based architecture. Cognitive Radio System (CRs) is a radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained[2]. A brief description of a cognitive radio system is given. Chief enabling technologies for the Cognitive Radio Systems are Geo-location database, Spectrum Sensing and Combined Spectrum Sensing Geo-location Database. Geo-location database is an entity that controls the TV spectrum utilization by unlicensed white spaces devices within a determined geographical area. Its sole objective is to enable unlicensed access to white space spectrum while protecting incumbent broadcasting services. Spectrum Sensing can be detecting unused spectrum and sharing it, without harmful interference to other users; an important requirement of the cognitive radio network is to sense empty spectrum. Detecting primary users is the most efficient way to detect empty spectrum. Combined Spectrum Sensing and Geo-location/Database is possible to use sense in parallel with access to the database.

In Simple words, we can say that Cognitive radio (CR) is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not, and instantly move into free channels while avoiding occupied ones. This optimizes the use of available radio-frequency (RF) spectrum through minimizing the interference to other users in the network.

2.2 TV White Space

With rising demand for bandwidth by various applications, researchers around the world have measured the occupancy of spectrum in different countries. The observations 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 (c.f. [3], [4], [5]). The overall usage of the analyzed spectrum ranges from 4.54% in Singapore to 22.57% in Barcelona, Spain [3], [4]. Licensed but unutilized or underutilized Television band spectrum is called as TV white space in the literature [6], [7]. These white spaces in the TV UHF band (470-590MHz) have been of particular interest owing to the superior propagation characteristics (from a received signal strength standpoint) [8]. Its status in the world is reviewed next. The sub-band 470–806 MHz in the UHF band (i.e. Channel 21– 62) is allocated primarily for terrestrial TV broadcasting service on a worldwide basis. In traditional radio system planning, co-channel TV broadcasting stations and hence their coverage areas are geographically separated so as to avoid radio interference.

As a result, some TV channels at certain locations are not used at all times. These TV channels are generally referred to as TVWS or TVWS spectrum [9] Radio spectrum is a scarce resource. With the continued increase in demand of spectrum for telecommunications services, some countries are/have been exploring ways to use the TVWS for low power telecommunications applications, such as wireless broadband Internet access [9]. In 1996, US Congress had set June 12, 2009, as the deadline for full-power television stations to stop broadcasting analog signals. TV Whitespace (TVWS) are unused/available gaps in TV broadcast spectrum (470-690MHz). Figure 1 represents the basic concept of TVWS.

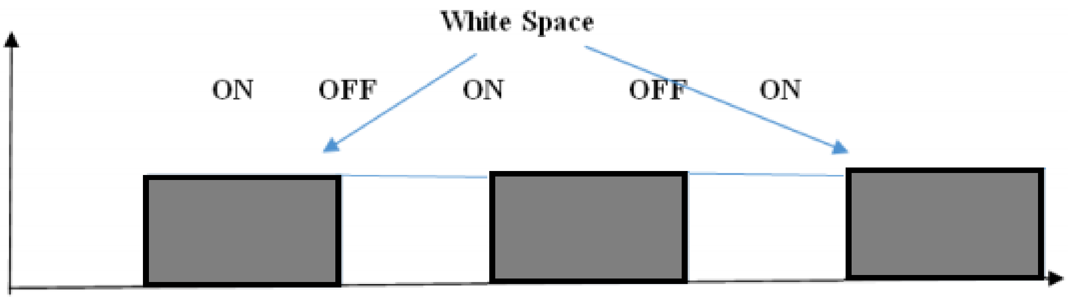

Fig. 1: Basic concept of TVWS [10]

2.3 Basic mechanism of TVWS

Basic Mechanism of TVWS are given below: [11]

(i) Devices only use the TV White Spaces channels specified by the database.
(ii) Devices are required to re-check the database for the list of available channels
(iii) Databases are prohibited from providing devices access to the channels occupied by incumbent operators.
(iv) Databases are required to maintain up to date lists of protected operators.
(v) Databases can block newly occupied channels to prevent further white spaces access.

Figure 2 shows the basic mechanism of TVWS.

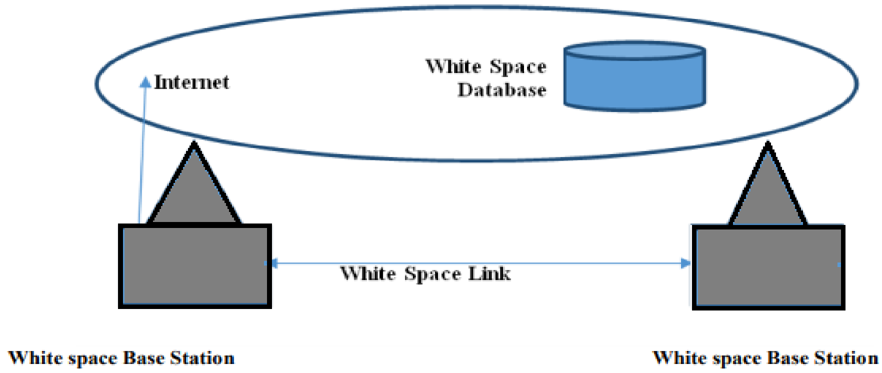

Fig. 2: Basic Mechanism of TVWS [10]

2.4 Standards and technologies to address TV white spaces

IEEE 802.11af has been designed by extending IEEE 802.11ac to support 8MHz channels and the use of a TV white space database to inform and control the use of spectrum by the devices [12]. IEEE 802.11af uses carrier sense multiple access at both the base station and the clients to share the spectrum. The spectral efficiency of 802.11af in a single antenna configuration varies from 0.3bits/s/Hz to 4.5bits/s/Hz, resulting in a maximum throughput of 35.6Mbps over an 8MHz channel. IEEE 802.11-based technologies including 802.11af and its variants, operate at a power level of 100mW-1W, and have a range of 1km in the last mile setting; and, it has been shown to work up to 15km with 10dBi sectoral antennas in a middle-mile setting. IEEE 802.22 is another IEEE standard designed for enabling broadband wireless access in TV white spaces [13]. IEEE 802.22 uses Orthogonal Frequency Division Multiple Access as the medium access (MAC) layer and uses centralized scheduling of the MAC resources by the base station. The spectral efficiency of IEEE 802.22 in a single antenna configuration varies from 0.6 bits/s/Hz to 3.1 bits/s/Hz, with a maximum throughput of about 19Mbps in a single channel. IEEE 802.15.4M is geared towards low-rate wireless personal area networks, with applications that include a machine to machine networks. A task group IEEE 802.15.4m is addressing which technologies should be enabled in the TV white spaces. IEEE 802.19 is a standard for enabling co-existence between different technologies, with the specific focus on TV white spaces [14]. IEEE 802.19 defines architecture and protocols for enabling co-existence between different secondary networks. Finally, 1900.7 have been established for advanced spectrum management and next-generation radios. In the future, we expect more technologies to be designed for operation over TV white spaces in using LTE [15] and IEEE 802.11ah. We note here that LTE technology can be adapted for TV white space by introducing design changes to the RF transmitter (for example, by tuning the RF section to operate in TV UHF band).

2.5 Geo-location database and white space device access rule

To ensure coexistence of the TV broadcasters with the secondary devices, geo-location databases have been mandated by the regulators FCC and Ofcom [6], [7]. All devices should have a location accuracy of 50m and must query a certified TV white space database to obtain an allowable channel with associated transmit power. The list of unoccupied (unutilized by primary) channel, the channel access schedule for 48hours, and the transmit power that is allowed and provided by the TV white space database.

2.6 TV white space availability in India

In India, the sole terrestrial TV service provider is Doordarshan which currently transmits in two channels in most parts across India. Currently, Doordarshan has 373 TV transmitters operating in the TV UHF band (more precisely, TV UHF band-IV in 470-590MHz) in India. The TV UHF band consists of fifteen channels of 8MHz each. In India, a small number of transmitters operate in this TV UHF bands; as a result, apart from 8-16MHz band depending on the location, the UHF band is not utilized in India! Comprehensive quantitative assessment and estimates for the TV white space in the 470-590MHz band for four zones of India have been presented by us in the literature [16]. It has been shown 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 [16] (see Fig. 1). E. TV UHF band utilization in India and its policy aspects TV white space in India is significantly larger than other countries reviewed above. The common approach to TV white space utilization is through the use of white space devices and associated country-specific regulations [6], [7]. Such this white space devices and regulations utilize the presence of DB (database) lookup, with transmit power limitations on the unlicensed user. While the 470-590MHz band has been licensed to TV broadcasting, its usage for rural broadband can be fundamentally different in India than through TV white space regulations. This fundamental difference is explained next. In the National Frequency Allocation Plan (NFAP) of 2011 [1], the spectrum in the frequency band 470-890MHz is earmarked for Fixed, Mobile and Broadcasting Services. India belongs to Region 3 of the ITU (International Telecommunications Unit) terrestrial spectrum allocations. In the 470-590MHz band, ITU allows Fixed, Mobile, Broadcasting services in the Region 3 [1]. As per India footnote 20 [1], fixed services in the 470-590MHz band are allowed in India within the existing ITU spectrum plan. This is in contrast with Region 1 (including Europe) where only broadcasting services are allowed in this band and Region 2 (including the United States) where fixed services are allowed only in 470-512MHz. Accordingly, fixed services can be allowed in 470-590MHz in India. This difference accommodates high-power transmissions by any fixed service (such as broadband base stations) in the 470-590MHz band in India. We suggest a license-exempt registered-shared-access based regulatory approach. Operators using TV white space spectrum may register with a database and may have to share a channel or a sub-channel with other users on the same channel in the vicinity. Further, different registered operators must cooperate and coexist to ensure high average spectral efficiency when compared to random access. Techniques such as LBT and other fit inter-operator co-operation techniques can be joined with database assistance.

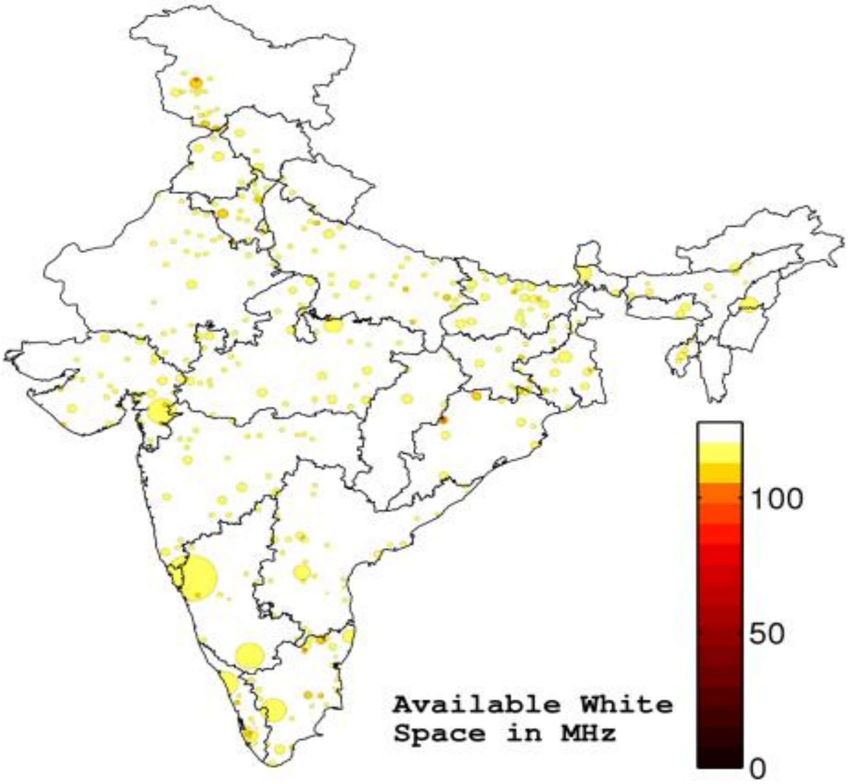

Fig. 3: Available TV white space in India is illustrated and observe that in almost all of the places, 100MHz of the spectrum is nearly unutilized

3. A BROADBAND ACCESS-NETWORK TOPOLOGY FOR RURAL INDIA

The 470-590MHz band, henceforth the UHF band for brevity, in India is heavily underutilized [16], and its radio propagation characteristics are much better than an unlicensed band such as 2.4GHz [8]. In fact, its propagation characteristics are suitable for non-line of sight connectivity. It is forecasted that a broadband access network can be provided by enlarging Internet coverage from a rural PoP provided by Bharat Net (an optical fiber point), by using TV white space in the UHF band. In such a scenario, broadband base stations working in the UHF band will give backhaul from villages to the PoP provided by Bharat Net. Each village can be served by an unlicensed-band or Wi-Fi cluster. This architecture can be used to provide affordable broadband access-network in (rural) India, and it results in a mesh-network of nodes operating in the UHF band as illustrated in Figure 4. The typical distance between nodes operating in 470-590MHz is around 1-5km. In summary, the PoP locations are provided by Bharat Net. The villages or hamlets can connect to wireless access points using 2.4 GHz Wi-Fi, which is an affordable short-distance technology. The end-devices (for the economy of scale and for ubiquity) will connect to the UHF band mesh network via the collocated 2.4GHz Wi-Fi access-points. At each Wi-Fi access-point, a UHF band node will be provisioned. Then these UHF band nodes can be used to backhaul the data from these Wi-Fi access points to the PoP (Point of presence) locations. The TV band base stations or relays can connect in different topologies:

(i) Point to point;
(ii) Multipoint to point, and
(iii) Multi-hop mesh network. Of these, we explore the most general topology of mesh-network.

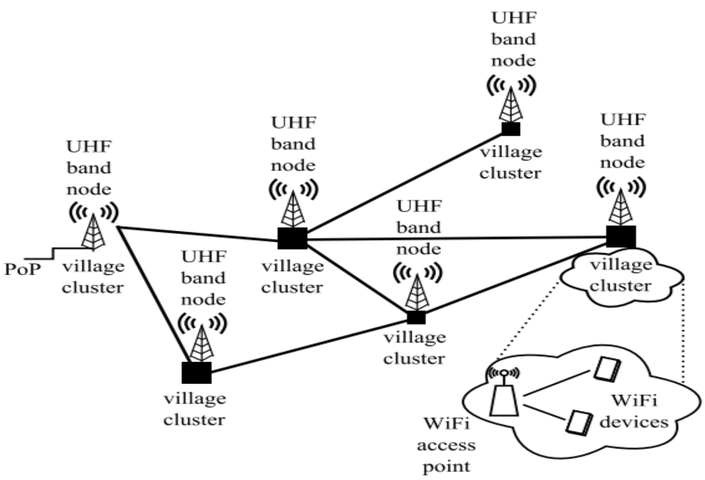

Fig. 4: It is assumed that there is a PoP with a UHF band node, to provide broadband access-network in nearby villages

Geographically sparse and distributed villages will form local 2.4GHz Wi-Fi clusters with Wi-Fi access points. Collocated with each Wi-Fi access point, a UHF band node (a client or a base station) will be provisioned. The data from the Wi-Fi networks will be backhauled to the PoP by these UHF band nodes.

The advantages of this broadband access-network are as follows: (i) the access technology Wi-Fi is affordable for the rural population in India; (ii) the backhaul is cheaper due to TV UHF band propagation characteristics (the license aspects can be handled using registered shared access, where multiple operators can coexist through database lookup [18]); and, (iii) the power consumption of each UHF band node is low (5-10W in our testbed), so that it can be powered through battery or solar energy.

4. ADVANTAGES, DISADVANTAGES, AND APPLICATIONS OF TVWS

4.1 The advantage of TVWS [17]

The key advantages of long range and good penetration for TVWS translate into the following advantages:

- **Lower cost of capital expenditure**: with longer range and better penetration, a smaller number of devices are required to connect up an area. As such CAPEX can be significantly reduced. Savings of up to 90% can be expected.
- **Lower cost of operating expenditure:** with license-exempt nature of TVWS as well as lesser installations (site access, rental, etc.), the cost of owning and operating a network is much lower than alternatives.
- **Easier and faster deployment:** TVWS can be deployed very easily and quickly. This also translates to a lower cost of deployment besides the non-tangible savings it gives such as minimal disruption to people & businesses, faster replacement of existing technologies, etc.
- **Better performance**: TVWS is lesser affected by rain, haze and other natural disturbances. Therefore, TVWS network is much more stable as compared to networks using higher frequencies such as 2.4 GHz or 5.8 GHz.
- **Lower latencies:** due to the larger available bandwidth, the latencies, especially for large networks are greatly reduced. Comparing to narrow-band IoT networks operating at 900 MHz bands, the latencies can be reduced by up to 100 times.
- **Reduced security risk:** networks with narrower bandwidth and thus smaller capacity are more susceptible to security attacks, e.g., when DDoS attacks happened, smaller capacity networks can be brought down easily. With larger capacity available for TVWS, the DDoS attack is more difficult.

4.2 The disadvantage of TVWS

- White space is variable and unlicensed. An assigned channel in one area may not be available in another. This could be a problem for some applications.
- Radios designed to use white spaces must be widely frequency agile. Wideband frequency synthesizers are available to make frequency assignment less of a problem, but power amplifiers are more difficult to make for such a wide band.
- When using unlicensed spectrum, you may at times be sharing space or adjacent channels. That means potential interference, such as from or to wireless microphones. For applications requiring good channel reliability, that may be a knockout factor.
- To be effective, any wireless device needs a good antenna. On the higher channels (500 MHz+), antennas are small. For example, a half-wave antenna at 700 MHz is only about 8 inches. At 300 MHz, it would be 18 inches. At 54 MHz, that translates to almost 9 feet for a half wave. Long antennas are not a big problem for fixed applications but become a major obstacle in portable devices.
- The FCC requires radios to access certified databases in real time to find an open channel, ensuring minimum interference. These databases list TV stations and other licensed and unlicensed wireless devices such as wireless microphones that can potentially interfere with one another in a given area. Device data such as location, type (fixed or mobile), power level, and other factors are included. It has taken time for these databases to come online, and the FCC is just now in the process of certifying them for use.
- There are no radio/network standards in place. Numerous proprietary standards have been tested but none has emerged as a clear favorite. Two are available now: Recently the IEEE‘s approved 802.22 standard and the forthcoming 802.11af Wi-Fi variation.

4.3 Potential Applications of TVWS [17]

The potential applications of TVWS can be broadly classified into 2 categories:

1. For broadband connectivity

- Rural Internet/Broadband
- Cable replacement (e.g., cable-less roll out of Wireless@SG)
- Private networks
- Fast deployment (e.g., during disaster, ad-hoc events)

2. For IoT connectivity

- Smart grid
- Smart street lighting
- Smart buildings
- Industry 4.0
- Precision agriculture

5. CONCLUSION

The availability of TV White Spaces presents a great opportunity for a better coverage and substantial bandwidth for the broadband communications. In this paper, I have articulated how UHF band can address the challenge to provide broadband connectivity to a billion plus population of India. One of the major impediments to providing broadband connectivity in semi-urban and rural India is the lack of robust and affordable backhaul. Even in urban areas, one of the major impediments for widespread deployment of Wi-Fi Hotspots is the lack of connectivity from Wi-Fi access points to optical fiber gateways. Fiber connectivity in terms of backhaul that is being planned (or provided) by the Government of India would reach only till the Gram

Panchayat in the rural areas. In such a scenario, the problem of connecting the Wi-Fi clusters to the optical fiber PoP can be addressed using a TV white space-based backhaul (middle-mile) network. I believe that a cost-effective solution for backhaul would require a license-free database assisted approach for TV white space spectrum management. Since the UHF band is sparsely utilized in India by the broadcaster, the challenge is not primary-secondary co-existence (as in many countries) but secondary-secondary co-existence. Multiple operators should be able to share the TV spectrum and co-exist. While listening before talk (LBT) approach as in IEEE 802.11af standard is one of the options for co-existence, it will pose challenges in rural regions with large cell radius, due to superior propagation characteristics of the sub-GHz spectrum. A combination of database assisted and LBT is a topic for future investigation for providing "primary" broadband connectivity by possibly many local operators. Dynamic resource allocation algorithm with fair sharing of resources between multiple operators (co-primary) is another area that requires more attention. Since TV band network is being proposed as middle mile network for backhauling Wi-Fi clusters, both Wi-Fi access points and TV band radios can be controlled through a Software Defined Networking (SDN) controller. This SDN controller can also be integrated with the Database controller. Finally, SDN controller can also be employed to dynamically configure flow routing in a more complex topology of multihop mesh based middle mile. An SDN enabled Policy based Radios deployed for middle mile fixed services can set the vision for 5G for India. Recently, the need for such vision for 5G has been also articulated by Eriksson and van de Beek [18].

I am currently investigating these topics as enhancements to existing TV white space standards. These topics are also under discussion in Telecom Standards Development Society of India (http://www.tsdsi.org).

6. REFERENCES

[1] WPC, "National Frequency Allocation Plan 2011," Department of Telecommunication, Government of India, Tech. Rep., 2011.

[2] SATRC Report on challenges of future technologies in spectrum management: cognitive radio, developed by SATRC Working Group on Spectrum, 13th Meeting of the South Asian Telecommunications Regulator's Council 18 – 20 April 2012, Kathmandu, Nepal.

[3] M. H. Islam, C. L. Koh, S. W. Oh, X. Qing, Y. Y. Lai, C. Wang, Y.-C. Liang, B. E. Toh, F. Chin, G. L. Tan, and W. Toh, "Spectrum survey in Singapore: Occupancy measurements and analyses," in Proc. of the third Cognitive Radio Oriented Wireless Networks and Communications, May 2008, pp. 1–7.

[4] M. Lopez-Ben ´ ´ıtez, A. Umbert, and F. Casadevall, "Evaluation of spectrum occupancy in Spain for cognitive radio applications," in Proc. of IEEE Vehicular Technology Conference. IEEE, New York, Apr. 2009, pp. 1–5.

[5] R. I. C. Chiang, G. B. Rowe, and K. W. Sowerby, "A quantitative analysis of spectral occupancy measurements for cognitive radio," in Proc. of the sixty-fifth IEEE Vehicular Technology Conference, April 2007, pp. 3016–3020.

[6] FCC 08-260, "Second report and order and memorandum opinion and order," US Federal Communication Commission, Tech. Rep., Nov. 2008.

[7] Ofcom, "Digital dividend: Cognitive access. Consultation on license-exempting cognitive devices using interleaved spectrum," Ofcom, UK, Tech. Rep., Feb. 2009. [Online]. Available: http://stakeholders.ofcom.org.uk/binaries/consultations/cognitive/state-ment/statement. Pdf

[8] J. D. Parsons, The Mobile Radio Propagation Channel Vol. 2. New York: Wiley, 2000.

[9] Telecommunications Regulatory Affairs Advisory Committee Development of TV White Space Technology, TRAAC Paper No. 6/2014.

[10] https://www.slideshare.net/hellomariajoseph/tv-white-space

[11] https://www.microsoft.com/en-us/research/wp-content/uploads/2016/02/spectrum-microsoft-super-wifi-overview.pdf

[12] IEEE 802.11af-2013, "Telecommunications and information exchange between systems - Local and metropolitan area networks - specific requirements - part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications Amendment 5: TV white spaces operation," IEEE Standard for Information Technology, Tech. Rep., Nov. 2013.

[13] IEEE 802.22-2011, "Standard for cognitive wireless regional area networks (RAN) for operation in TV bands," IEEE Standard, Tech. Rep., Jul. 2011.

[14] IEEE 802.19.1-2014, "Telecommunications and information exchange between systems – Local and metropolitan area networks – specific requirements – part 19: TV white space coexistence methods," IEEE Standard for Information Technology, Tech. Rep., 2014.

[15] http://www.3gpp.org/dynareport/36-series.htm

[16] G. Naik, S. Singhal, A. Kumar, and A. Karandikar, "Quantitative assessment of TV white space in India," in Proc. of the Twentieth National Conference on Communications, Feb. 2014, pp. 1–6.

[17] http://www.ipi-singapore.org/technology-offers/tv-white-space-super-wi-fi

[18] M. Eriksson and J. van de Beek, "Is anyone out there? 5G, rural coverage and the next one billion," IEEE Communications Technology News, Tech. Rep., Nov. 2015.

