Towards Enabling Broadband for a Billion Plus Population with TV White Spaces

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Abstract

One of the major impediments to providing broadband connectivity in semi-urban and rural India is the lack of robust and affordable backhaul. Fiber connectivity in terms of backhaul that is being planned (or provided) by the Government of India would reach only till rural offices (named Gram Panchayat) in the Indian rural areas. In this exposition, we articulate how TV white space can address the challenge in providing broadband connectivity to a billion plus population within India. The villages can form 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.

The amount of TV white space present in India is very large when compared with the developed world. Therefore, we discuss a backhaul architecture for rural India, which utilizes TV white spaces. We also showcase results from our TV white space testbed, which support the effectiveness of backhaul by using TV white spaces. Our testbed provides a broadband access network to rural population in thirteen villages. The testbed is deployed over an area of 25km², and extends seamless broadband connectivity from optical fiber locations or Internet gateways to remote (difficult to connect) rural regions. We also discuss standards and TV white space regulations, which are pertinent to the backhaul architecture mentioned above.

Index Terms

Wireless networks, wireless mesh networks, access networks, TV white spaces.

I. INTRODUCTION

In the past decades, India has witnessed ever-increasing wireless telecom connectivity. There are over 940 million wireless telecom subscribers with a tele-density of over 77, and India is 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 tele-density is 46 (compared against the urban tele-density 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 as a fraction of total revenue; (ii) high capital and operation expenditure (including license fees); (iii) affordable backhaul which is exacerbated due to a very large population, (iv) energy cost which is worsened 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, Government of India has been working with the initiative BharatNet (formerly National Optical Fiber Plan or NOFN). Within BharatNet, which is being implemented in two phases, point of presence (PoP) with optical connectivity at all village offices named Gram Panchayat will be provided. It must be noted that mobility, at the moment, is not a major driver for broadband; instead, primary (fixed) broadband service is the biggest requirement in rural India.

According to the National Telecom Policy, definition of broadband is a 2Mbps connection. The current broadband subscriber-base is around 15.35 million in India. The targets of the Government of India are high and
mighty; by 2020, the Government of India plans to have a broadband subscriber-base of 600 million. When coupled with 2 Mbps definition of broadband, a subscriber base of 250 million in 2017, with 250 GB/month at 2 Mbps will generate 100 Exabytes of data per month in India alone. This is 8x larger than the expected global mobile traffic by 2017! For example, consider the city of Mumbai, the population density is 21,000/km². Approximately 34% is wetland or forest. As a result, in some areas the population density is as high as 100,000/household size of 4, and if 100% homes have broadband, the amount of data generated will be 50 Gbps/km². Assuming 4 cells with radius < 500 m, about 12 Gbps per cell capacity will be required. The current wireless technologies including Long Term Evolution (LTE)/LTE-A will be unable to address this. One of the solutions, therefore, would be to deploy small cells such as dense Wi-Fi hotspots. However, due to non-availability of ubiquitous fiber, backhauling of small cells is a challenge. We propose that TV UHF band radios can be used to backhauling these dense Wi-Fi cells.

On the rural front, there are 250,000 village offices named Gram Panchayat in India. The total number of villages is 638,619, so that each Gram Panchayat serves about 2.56 villages on an average. Each village has around 4 hamlets at the periphery on an average. As mentioned earlier, BharatNet is an ambitious plan to provide PoP at Gram Panchayat (offices) with optical fiber backhaul. Since the villages can be at a maximum distance of a few kilometers from the Gram Panchayat, BharatNet will allay but not solve the problem of rural broadband in India. In each hamlet or village, a wireless cluster can be formed (for example, by using a Wi-Fi access point), but backhaul of the data from access points remains a challenge. We envisage that TV white spaces (in the UHF band) can be utilized to backhaul data from village Wi-Fi clusters to the PoP provided by BharatNet.

This vision raises the following important questions—Can TV UHF band/TV white spaces be used to solve the above-mentioned backhaul problem? How has the TV UHF band/TV white spaces utilized in the rest of the world? How much TV white space is available in India and how does it compare with other countries? What network topologies in the TV UHF band can be exploited to solve the backhaul problem? What results are obtained from actual experimental testbed while performing backhaul in the TV UHF band over sparsely populated rural areas? These questions will be subsequently answered in this article.¹

II. TV white space overview

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 TV band spectrum is called as TV white space in the literature [6], [7]. These white spaces in the TV UHF band (470–590 MHz) 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.

A. TV white space in various countries

The amount of available TV white space varies with location and time. The available TV white space depends on regulations such as the protection margin given to the primary user, height above average terrain, transmission power of secondary users, and separation of unlicensed user from the licensed ones. 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. TV white space estimation has been done in countries like the United States (US), the United Kingdom (UK), Europe, Japan, and India [9], [10], [11], [12], [13]. For instance, in Japan, out of 40 channels, on an average, 16.67 channels (41.67%) are available in 84.3% of the areas [12]. The available TV white space by area in Germany, UK, Switzerland, Denmark on an average ranges between 48% to 63 out of the 40 TV channel bands [11]. It must be noted that in these TV white space studies, the IMT-A (698–806 MHz) band is also included.

FCC regulations in the US and Ofcom regulations in the UK have allowed for secondary operations in the TV white spaces [6], [7]. For example, FCC regulations declare a band as unutilized if no licensed-user (primary) signal

¹In a mobility driven setup, TV white space testbed has been used in Microsoft Corporation, Redmond to backhaul data from a Wi-Fi cluster in a moving shuttle [2].
is detected above a threshold of $-114\text{dBm}$ [6]. 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 starts operation.

**B. 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 [14]. 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 a 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 [15]. 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 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 specific focus on TV white spaces [16]. IEEE 802.19 defines an architecture and protocols for enabling co-existence between different secondary networks. Finally, 1900.7 has 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 including LTE [17] and IEEE 802.11ah. We note here that LTE technology can be adopted 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).

**C. Geolocation database and white space device access rules**

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

**D. 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 [13]. 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 [13] (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 for TV white space utilization is through the use of whitespace devices and associated country-specific regulations [6], [7]. Such whitespace devices and regulations utilize the presence of database lookup, with transmit power limitations on the unlicensed user. While 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 terrestrial spectrum allocations. In the 470-590MHz band, ITU permits 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 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 suitable inter-operator co-operation techniques can be combined with database assistance.

III. A BROADBAND ACCESS-NETWORK TOPOLOGY FOR RURAL INDIA

The 470-590MHz band, henceforth the UHF band for brevity, in India is heavily underutilized [13], and its radio propagation characteristics are much better than and unlicensed band such as 2.4GHz [8]. In fact, its propagation characteristics are suitable for non-line of sight connectivity. It is envisaged that a broadband access network can be provided by extending Internet coverage from a rural PoP provided by BharatNet (an optical fiber point), by using TV white space in the UHF band. In such a scenario, broadband base stations operating in the UHF band will provide backhaul from villages to the PoP provided by BharatNet. Each village can be served by an unlicensed-band 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 Fig. 2. The typical distance between nodes operating in 470-590MHz is around 1-5km.

In summary, the PoP locations are provided by BharatNet. The villages or hamlets can connect to wireless access points using 2.4GHz Wi-Fi, which is an affordable short-distance technology. The end-devices (for 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 UHF band nodes can be used to backhaul the data from these Wi-Fi access points to the PoP 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.
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. The next section highlights the results of our testbed implemented in the multi-hop mesh topology, in a cluster of villages near Mumbai, India.

IV. THE FIRST TV WHITE SPACE TEST-BED IN INDIA

An instance of the mesh-network proposed in the previous section has been realized in a testbed at Khamloli, Maharashtra, India. The testbed is located in the Palghar district at about 107km distance from Indian Institute of Technology Bombay. It is the first TV white space testbed in India. The layout of villages surrounding Khamloli is illustrated in Fig. 3. The typical distance between two villages is in the range of 5km as mentioned, and the testbed is deployed over an area of 25km². Khamloli village node forms the PoP in this layout with a 20Mbps optical fiber link. With Khamloli village as PoP, a mesh-network is setup to extend Internet from Khamloli (wirelessly in the UHF band) to the surrounding villages. The testbed provides a broadband access-network to the rural population in thirteen villages or hamlets. Our testbed consists of 10 UHF band nodes functioning as client and 1 UHF band node as base-station. The clients in UHF band are connected to Wi-Fi hotspots to provide Internet access.

A. Topographic details of the testbed

To give an idea about the propagation characteristics of RF signal, the topographical settings of various tower locations and UHF band nodes are described. It must be noted that there are significant differences in the topographic settings between Khamloli (PoP) and the other towers. There are four UHF band nodes setup as base-station nodes. These result in Khamloli-Maswan, Khamloli-Haloli, Khamloli-Ganje, and Khamloli-Pargaon (see Fig. 4(a)) links. There is no line of sight in Khamloli-Maswan and Khamloli-Ganje links. There is heavy vegetation in Khamloli-Ganje link. All other links have moderate vegetation.

There are seven UHF band nodes setup as client named Khamloli 1, Khamloli 2, Bahadoli 1, Bahadoli 2, Dhuktan 1, Dhuktan 2, and Dhuktan 3. These UHF band nodes are setup at a height ranging in 4-6meters, with small houses in between. Khamloli 1, Khamloli 2, Bahadoli 1, and Bahadoli 2 have line of sight with Khamloli PoP.
Fig. 3. An example of Indian rural topology is illustrated. Khamloli village has a 20Mbps optical fiber link to the Internet. A wireless mesh-network can be setup with Khamloli as the PoP to provide a broadband access-network in the nearby villages, while leveraging on the unutilized UHF band.

But, Dhuktan 1 and Dhuktan 3 do not have line of sight while Dhuktan 2 has partial line of sight with Khamloli PoP. Vegetation is large only in Dhuktan 3 link (see Fig. 4(b)).

Fig. 4. Khamloli is a PoP in our testbed. (a) The long-distance links of the testbed are illustrated. Each tower is equipped with a UHF band base-station. (b) The short-distance links of the testbed are illustrated. Khamloli tower has a UHF band base-station, while other nodes have UHF band clients.

The UHF band node at Khamloli PoP is a base-station, has an omnidirectional antenna, and is mounted at a height of 30 meters. At each location, a suitable site was identified for setting up the UHF band equipment and associated accessories including power supply. At every location marked in the testbed layout (see Fig. 4(b)), Wi-Fi routers have been installed to test the Internet connectivity. The customer premises equipments are Wi-Fi enabled devices such as tablets or smartphones.
B. Our developed economical UHF band node prototype

Products based on IEEE 802.22 and IEEE 802.11af standards are available off-the-shelf, but are expensive (USD4000-5000 for base-station and USD1000-2000 for client). From an affordable broadband service point of view, we decided to develop a low-cost prototype of UHF band node; and, our developed prototype costs USD650 per UHF band node. We adopted the approach of using standard IEEE 802.11g Wi-Fi with radio-frequency of 500MHz. Our device has OpenWrt operating system ported on it. This enabled us to implement the Protocol to Access White Space (PAWS), an Internet Engineering Task Force (IETF) standardized protocol. Our prototype comprises of a commercially available off-the-shelf Wi-Fi routerboard that can connect with an RF card having a mini PCI interface. The RF card converts the baseband signal to 2.4GHz, which is translated to 500MHz (UHF band) by a downconverter. Few pictures from our testbed illustrating the box of prototype are shown in Fig. 5.

Fig. 5. Photographs of some UHF band nodes (clients) from Fig. 4 are shown. (a) Dhuktan 2 client is mounted at the top of a hill with no houses around. (b) and (c) UHF band clients are typically mounted at a height of 4-6 meters.

C. The Coexistence Handler—a UHF Band Database for India

The testbed’s UHF band devices query an OpenPAWS database setup by our research group to select the frequency of operation, to avoid interference to any terrestrial TV services in other geographical regions of India [19]. OpenPAWS client was implemented in OpenWrt (ported on TV UHF band node), while the OpenPAWS server was implemented in Linux. The OpenPAWS based database server implementation was tested to ensure its functioning with our testbed. An error message is generated by the OpenPAWS server in the following three scenarios: (i) the UHF band device is outside the regulatory domain of the TV white space database; (ii) the UHF band device sends an AVAIL_SPECTRUM_REQ before initialization and registration; or, (iii) there are no channels available at the location of the UHF band device. In our setup, the locations of the UHF band devices are known since it is a fixed network. This rules out error in (i). The error in (ii) can be controlled by proper programming. In India, it has been shown that there is a channel available at any point [13]. Therefore, OpenPAWS server’s response will be a list of available channels with transmit power allocation.

For the Khamloli village (PoP) in the testbed, the OpenPAWS database declared Channel 1 to Channel 15 as available since the Channels are available for transmission [13]. The transmit power was restricted to 30dBm. After assigning the power and channel to various UHF band nodes, the database is updated to reflect the same. The

2We also experimented with IEEE 802.22 standard devices (such as those available from Carlson Wireless), however, large scale deployment of testbed did not use them.

3Note that any Channel in 470-590MHz could be used since the entire band is free in the vicinity of Khamloli!
database created is open for public access [19] and can be used to view the list of all TV towers operating in India in the UHF band along with all operational parameters. It also displays TV towers operating on any particular channel along with the tower’s coverage area calculated in [13].

D. Results obtained from the testbed

The results that were obtained with our testbed after extensive experimentation over a few months are highlighted in this section. These comprise of throughput analysis for various links, and the variation and latencies observed in the throughput. An ATM machine use-case is also explained towards the end of this section.

There are many point to point links in our testbed, from which we exemplify one. This is a long-distance with line of sight (Khamloli-Pargaon). For a bandwidth of 5MHz, the obtained uplink and downlink throughputs (while using UDP as well as TCP) are illustrated in Fig. 6. In the plots, observe that the received signal to noise ratio (SNR) varies since the transmit power is kept constant (at 27dBm with 8dBi antenna gain) and the receiver’s distance and associated conditions vary. Consistently a throughput of 4-5Mbps (in TCP) and 5-6Mbps (in UDP) were obtained for the uplink as well as downlink. The tool used to monitor the network was iperf. TCP and UDP throughputs over each link were computed using 500 different samples.

The variation of latencies was also examined by 25000 randomly taken measurements. Two extreme-range of wireless topographies were considered—Khamloli-Ganje which represents a 6.7km long-distance link at 5MHz bandwidth (large distance and low bandwidth), and Khamloli-Dhuktan which represents a 2.3km moderate-distance link at 20MHz bandwidth (small distance and large bandwidth). The latencies for Khamloli-Ganje link varies in 2-15ms, while its UDP throughput varies in 5.6-8Mbps. The latencies for Khamloli-Dhuktan link varies in 2-11ms, while its UDP throughput varies in 11-17Mbps. These results are very exciting and promising!

High speed Internet access has been provided to the villagers in Khamloli, Bahadoli and Dhuktan using Wi-Fi hotspots deployed at 10 locations across 3 villages and 3 kiosks one in each village. About 60 villagers from three villages and surrounding hamlets (pada) have been trained as ‘e-Sevaks’ (electronic serviceman). An e-Sevak assists other villagers in using Internet services for simple tasks like filling college forms, paying electricity bills, and booking of train tickets. Kiosks set up in the three villages are run by these e-Sevaks on a daily basis for three hours for this purpose. E-Sevaks have been given tablets for getting familiar with these Internet services.

An automated Teller Machine (ATM) provided by TATA Indicash is setup at Dhuktan Gram Panchayat (village office) in order to demonstrate the use of e-Finance capabilities of TV white space for the rural areas. The ATM machine is on a different private LAN which is tunneled through a Border Gateway Protocol (BGP) route from Khamloli PoP to the ATM network. Tata Teleservices Limited and Tata Communications provisioned the Multi-Protocol Label Switch (MPLS) leg of 64kbps at Khamloli, which was connected to security gateway application from Pfsense (http://www.pfsense.com) by configuring one of the optional ports as a wireless area network (WAN). The ATM machine connects to a Wi-Fi point to point link by Ethernet; this point to point link is connected to a Wi-Fi access point, which connects with the PoP at Khamloli via TV white space network.

![Fig. 6. The elevation profile of Khamloli-Pargaon link, and the obtained throughput for TCP/UDP protocols are shown. The channel bandwidth was 5MHz, and the transmit power and antenna gain were 27dBm and 8dBi, respectively.](image-url)
V. Conclusions and Future Work

In this paper, we have articulated how UHF band can address the challenge in providing broadband connectivity to a billion plus population of India. As outlined in the paper, 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.

We believe that a cost effective solution for backhaul would require a license exempt database assisted approach for TV white space spectrum management. Since 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 listen 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 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 Database controller. Finally SDN controller can also be employed to dynamically configure flow routing in a more complex topology of multi-hop mesh based middle mile. A 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 [20].

We are 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.tsdssi.org).

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