TVWS Radio Spectrum Utilization: Use Case of India-Looking Forward

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Abstract

The complexity of wireless networks requires careful design with special attention to energy and bandwidth efficiency. The energy efficiency is of more importance due to increasing penetration of wireless systems in different battery-operated applications as well as more conscious global view on the need for "Greening the Earth". Bandwidth efficiency is very important parameter, because it relates to frequency spectrum, which is naturally scarce resource. Thus spectrum sensing is an important part of "Green Engineering". The "Cognitive Radio" (CR) technology sheds new light on unavailability of spectrum by managing radio resources in more systematic and efficient way. Around the Globe there is a coordinated move for Digital Switch over (DSO) by discontinuing analogue television transmission. This "Digital Dividend" (DD) has created a new spectrum opportunities for many new wireless technologies. We focus on the scope and nature of opportunities for white space created by DD for Indian scenarios. We discuss use cases for the exploitation of Television White Space (TVWS) suitable for rural India based on user's and BS geo-location and user's mobility followed by QoS requirements and recent regulatory activities.

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1 Introduction

Although spectrum is seen as a scarce natural resource, measurements show that often there are moments in time and space where the spectrum is not being fully utilized by the allocated services and therefore it is being used inefficiently [1].

ITU predicted that 1720 MHz spectrum will be required by the year 2020. Many new wireless services/applications cannot be rolled out due to non-availability of spectrum [2], which demands dynamic allocation of spectrum instead of static [1]. CR would help to meet the ever increasing demand of radio spectrum and help in managing resource in more systematic and in more efficient way. The basic idea of CR is to reuse the spectrum whenever it is vacant by the primary/licensed users (PUs). The secondary/unlicensed users (SUs) are required to perform the frequent spectrum sensing for detecting the presence of PUs [3]. TV switchover to full digital broadcast service (DD) creates new spectrum opportunities due to higher spectral efficiency compared to analogue services. This TVWS opens the door for CR technology.

Spectrum regulatory bodies in various countries are studying the pro and cons of CR devices. Some countries have already made provisions for CR. FCC has already made provision for use of CR device in TV bands [4]. Ofcom from UK has also studied CR in their spectrum framework review and made provision for use of unlicensed cognitive devices in TV band by using TVWS [5]. CEPT has implemented a CR based device to operate in TVWS [6]. The survey of spectrum utilization in India [7] is similar to other countries. The plot for spectrum usage at Mumbai and time [7] for a frequency band of 600–800 MHz is as shown in Figure 1. This plot of spectrum utilization for 600–800 MHz shows that the spectrum in these bands in India is underutilized and can be opened for CR application.

The organization of the paper is as follows: Section 2 describes the DD scenario. Section 3 deals with opportunities in TVWS, followed by use cases for TVWS usage in Section 4. Section 5 discusses QoS in TVWS cognitive access, followed by the regulatory aspects in TVWS in Section 6. Finally, in Section 7 we present the conclusion.

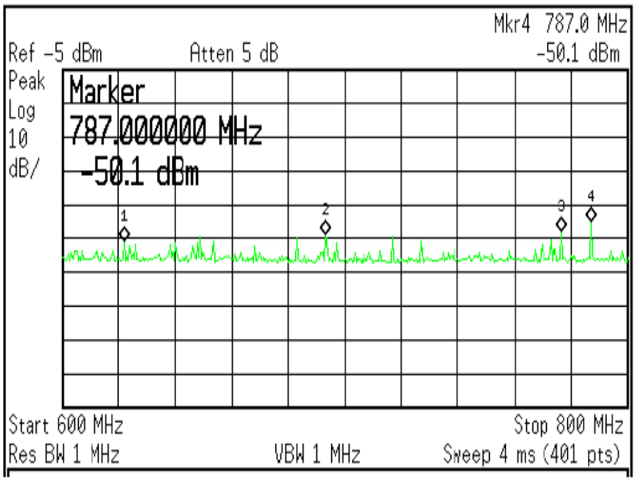

Figure 1 Frequency utilization in 600–800M Hz at one location (Mumbai) in India [7].

2 Digital Dividend

The DD scenario at international and in India is analyzed in this section.

2.1 International Scenario

The digital switchover process is underway but complete analogue switch-off is not easy. The full switch off of analogue services can have terrible consequences if viewers were not adequately prepared. So DD will require careful planning and the involvement of the entire broadcast industry.

The process of analogue switch-off will differ in countries depending upon the market configuration. Table 1 indicates an analogue switch-off (ASO) situation in various countries. The countries that have not done full ASO can take useful lessons from that have completed ASO about understanding best approaches, pitfalls that should be avoided, can help to ensure a successful process.

2.2 Indian Scenario

In India the Wireless Planning and Coordination (WPC) is the national radio regulatory authority responsible for frequency spectrum management. The National Frequency Allocation Plan (NFAP) forms the basis for development and manufacturing of wireless equipment and spectrum utilization. Accord-

Table 1 The ASO situation in various countries.

Country	Completion of ASO
UK, Luxemburg, the Netherlands, Finland, Sweden, Germany, Belgium, Denmark, Estonia, France, Czech Repulbic, Croatia, Switzerland, Malta, Slovenia, Japan, South Korea , Malta	Completed
Bulgaria, Cyprus, Greece	By the end of 2012
Australia, New Zealand, South Africa	2013
Pan-Arab	2014
Poland, Slovakia, India, Russia, Tunisia, Albenia, Cambodia	2015
Chile, Colombia	2017

Table 2 Spectrum allocation 470–806 MHz in India.

Band	Spectrum	Number of TV channels available in analogue mode/other services	TV channel number
UHF Band IV	470–582 MHz	14	21 to 34
		Mobile TV using DVB-H	26
UHF Band V	582–806 MHz	28	35 to 62
	610–806 MHz	BSNL, Defense operate point to point microwave links	–
	746–806 MHz	Public Protection and Disaster Relief (PPDR)	–
	> 806 MHz	Fixed, mobile services for transmission of data/voice, cellular mobile services	–

ing to NFAP-2011 [8], the vacant bands due to DD are allocated to other important services like International Mobile Telecommunications(IMT) services, data broadcasting, High definition TV(HDTV), ultra HDTV, mobile TV services, Super Hi-Vision (SHV) TV and Digital Terrestrial Television (DTT), etc. [9, 10].

In India, the 470–806 MHz band has been allotted to fixed, mobile broadcasting services on primary basis. In *UHF Band IV* (470–582 MHz) 14 TV channels, each of 8 MHz bandwidth, are available. Doordarshan is the only Government broadcaster that operates digital transmitters in four metros in this band. In *UHF Band V* (582–806 MHz) 28 TV channels each of 8 MHz bandwidth are available. Defence and BSNL are operating point-to-point microwave links in 610–806 MHz. Public Protection and Disaster Relief (PPDR) has some spots earmarked in 750–806 MHz. The UHF Band V above 806 MHz is also shared with other users of spectrum such as fixed and mobile services for transmission of data/voice and video (see Table 2). The complete switchover to digital transmission is a very challenging task in

India considering huge analogue TV sets in rural India and in more populated parts of India but it will be completed in 2015. This will be a slow process and hence Doordarshan suggested simulcast of analogue and digital transmission till complete switch off of analogue transmission [9].

3 Opportunities in TVWS

At present no specific regulations have been made for CR technology in India. CR technology should be implemented in those frequency bands where spectrum utilization is not high, the location of the base station is known and the receivers are robust against interference.

In this paper IEEE 802.22 and IEEE 802.11af standards are discussed which are based on CR operating in TVWS. The IEEE 802.22 standard is already finalized and in operation but the standardization process for IEEE 802.11af is not yet finished [11].

There are various opportunities for exploiting TVWS in an efficient manner. Some of them are discussed below.

3.1 Wide Area Coverage in Rural Areas (IEEE 802.22)

IEEE 802.22 wide regional area network (WRAN) aims to provide fixed wireless access with a typical cell radius of 33 km with Effective Isotropic Radiated Power (EIRP) of 4 W and a maximum of 100 km in rural and remote areas using CR technology in TVWS [12]. The spectral efficiency of 802.22 systems ranges from 0.5 to 5 bit/s/Hz. At an average value of 3 bit/s/Hz, the capacity of a 6 MHz channel can reach 18 Mbit/s. Broadband to rural areas might therefore prove to be very cheap.

3.2 Low Power Broadband: IEEE 802.11af

In some urban areas in e.g. Asia, Europe and USA there is not much white space (WS) for high power systems like fixed unlicensed devices that would operate from a fixed location and could be used to provide commercial services such as wireless broadband Internet access. However, there could be a potential for low power broadband systems like "portable/personal" unlicensed devices, such as wireless in-home local area networks (LANs) or Wi-Fi-like cards in laptop computers that exploit smaller portions of TVWS. 802.11af is a modified 802.11 standard, which operate in a range of TVWS using the properties of CR. The requirements specification of 802.11af system is formed, but the standardization process is not yet finished. It is also called as “White-Fi” or “Super Wi-Fi” (“White” due to work in unused TV band and “Super” due to its cognition properties).

Some promising applications of IEEE 802.11af with respect to Indian scenario are:

- *Remote monitoring of power plant*: nuclear power plants (e.g. Tarapore) or hydro power plants (Pophali) can be remotely monitored by smart grid technologies that exploits TVWS in order to improve system operation and control, manage its demand of electrical power, provide broadband Internet access to under-served areas (like tribal villages: Himachal Pradesh, Arunachal Pradesh and Mizoram, etc.) [13].
- *Backhaul for Wi-Fi* in campuses, businesses, hotels, theatres (Wi-Fi could be IEEE 802.11af or IEEE 802.11a/b/g/n) avoiding costly, time consuming and challenging cabling issues.
- *Traffic monitoring and precautionary measure for prevention from accident*: Traffic cameras can be installed at all major accident prone intersections to provide real-time traffic monitoring, reduce congestion, travel time and also fuel consumption.
- *Anti theft measure*: Theft like-car/personal/bicycle/motorcycle could be avoided by wireless camera connected to police for surveillance and also radios can be incorporated in city parks availing free Wi-Fi access to residents and city workers for surveillance.
- *Remote monitoring and managing heavy wetland areas* like the north-east states of India (Assam, Manipur, Sikkim, Mizoram and Nagaland) to comply with EPA regulations because these areas are hard to get, utilizing the WS network.
- *Medical monitoring, environmental monitoring, vehicular communications, cellular networks offloading and ad-hoc networks* (e.g. internal sensor network or mesh network communication).
- *Digital video broadcast for handheld (DVB-H) system with cognitive access*: DVB-H could be utilized as an unlicensed secondary network together with licensed network such as DVB-T, operating in UHF bands. Mobile TV providers prefer this band as it provides balance in the antenna size and coverage. It can be integrated with car terminals, portable digital TV sets and handheld portable convergence terminals. Still the big challenge with DVB-H by mobile operators is the issue of suitable business and revenue models. When implementing DVB-H based on CR, the following design considerations must be taken into account:

  - Time slicing, in order to reduce the average power consumption of the terminal and to make possible smooth handovers. The time-slicing technique, enables considerable battery power-saving. Further, time-slicing allows soft handover if the receiver moves from network cell to network cell.
  - An enhanced error protection scheme on the link layer to increase reception robustness for indoor and mobile contexts.
  - In-depth symbol interleaver, for further improvement of the transmitted signal robustness in impulse noise conditions and mobile environment.

- *Public safety application with CR approach exploiting TVWS*: all public safety communication infrastructures in India use narrowband radios which limits them to 2-way voice communications with no inherent support for high-bandwidth transmission requirements such as interactive video communication, remote video surveillance of security or disaster sites and do not provide the level of secure communication required by India's security forces resulting in easy leak of information to rogue entities, e.g., terrorists. Although TETRA enhanced data services are available through WIMAX and LTE, but they are not sufficiently reliable as required by public safety measures. As Opportunistic spectrum allocations provide greater capacity for overloaded network and dynamic reconfiguration capability to better manage load and connectivity. The cognitive access to TVWS can be a viable alternative of a common band used for Public Safety. The CR spectrum broker can easily integrate a prioritizing mechanism that assigns TVWS for a specific disaster area based on spectrum availability information provided by the geo-location database.
- *Programme Making Special Events (PMSE)*: PMSE applications have already been already using TVWS as unlicensed users .As a result of DD, the amount of spectrum resources for PMSE were reduced. At the same time, there is an increasing demand for spectrum for PMSE [6]. The PMSE in TVWS employing CR will provide the improvement in terms of spectrum efficiency, reliability and productivity of existing applications.

  Typical applications of PMSE are, e.g., temporary connectivity to manage people assembled for exhibitions, festivals, election campaign, medical campaign, community awareness sessions and breaking news.

- *LTE extension (GSM/3G/HSPA)*: LTE has considerable flexibility, scalable channel bandwidths from 1.4 to 20 MHz which optimizes the use of radio spectrum by making use of new spectrum and re-farmed spectrum opportunities. It is best solution for deployment as a next generation cellular communication infrastructure. Operators evolving to LTE from GSM/WCDMA/HSPA will maintain full backward compatibility with legacy networks. The TVWS could also be exploited for managing peak traffic by obtaining and sharing channels on a temporary basis.
- *Femto-cell for wireless broadband in TVWS*: Femto-cells can be the next deployment choice for indoor environment as a complement to micro-cells for enhancing coverage and capacity in TVWS which can penetrate through walls and buildings, based on the concept of intra-operator spectrum WS reuse, multi-operator spectrum sharing and multi-service spectrum reuse exploiting the spectrum of multiple operators and of multiple non-cellular services (e.g. DTV broadcasts).
- *Rural broadband access-empowering rural India*: e-governance-agriculture-learning-healthcare and e-animal husbandry utilizing TVWS opportunities could benefit to the rural India by providing knowledge based economy, like in decreasing farmer suicides by boosting agriculture Gross Domestic Product (GDP), in decreasing primary school drop-out rate by providing video based trainings and in decreasing mortality rate viz. video conferencing for e-cardio testing and e-diagnosis facilities. Here we have given the example of e-animal husbandry application (see Figure 2). An online disease reporting system known as the "National Animal Disease Reporting (NADR)" system can be implemented using CR networks utilizing TVWS. With this system farmers will benefit by providing wireless connectivity among various units like Taluka unit, district unit, state unit, centre unit, veterinary (Vet.) dispensary, Taluka level NGO, etc. The Central Unit at Department of Animal Husbandry and Dairies (DAH&D) would be responsible for analysis and maintenance of data. All the disease related information would be available online, which will ensure transparency and benefit of all concerned.

Table 3 reflects the scenarios and typical ranges in IEEE 802.11 af standard utilizing TVWS based on above applications studied in Section 3.2.

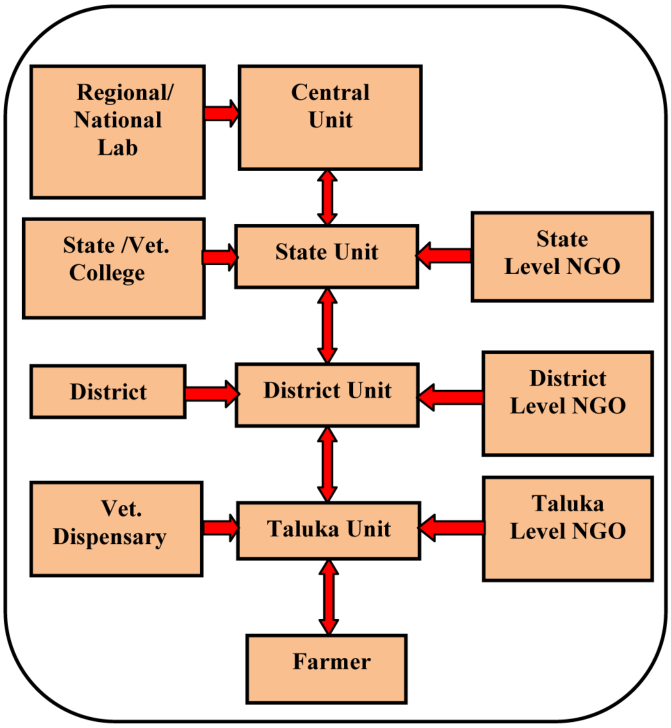

Figure 2 NADR System [15].

Table 3 Scenarios and typical ranges in IEEE 802.11 af standard based on CR networks utilizing TVWS.

Scenarios	Ranges
Backhaul	10 km
LTE extension in TVWS	0–10 km
Rural broadband	0–10 km
Terminal to terminal cellular	10–1000 m
Ad-hoc network in TVWS	0–100 m
Femto cell in TVWS	0–100 m

4 Use Cases for TVWS Usage

The ETSI RRS technical committee [13] is currently focusing on TVWS standardization, especially on both cellular and short range applications. These key use cases are implemented depending on user's and Base Station (BS) geo-location and user's mobility from rural India point of view.

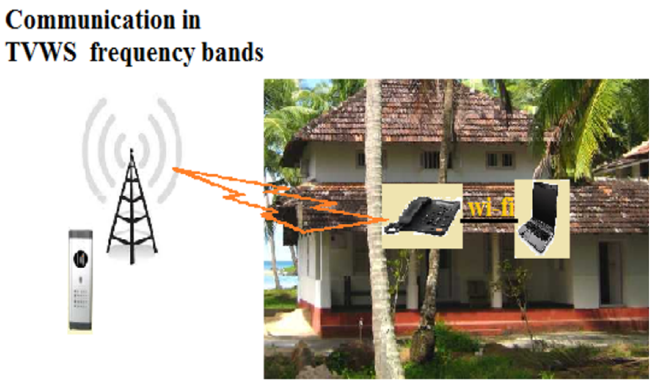

Figure 3 Mid/long range wireless access: no mobility (Ratnagiri, Maharashtra).

4.1 Use Case: Mid/Long Range Wireless Access

Internet access is provided by BS to the end user by exploiting TVWS over the ranges similar to the cellular system 0 to 10 km depending on user's mobility [15]. It is further classified as follows.

4.1.1 Mid/Long Range: No Mobility

Wireless access is provided from BS towards fixed mounted home access point/base station (see Figure 3). The geo-location for both BS and fixed device are well known.

4.1.2 Mid/Long Range: Low Mobility

In this scenario, wireless access is delivered from BS towards mobile devices where the user has low mobility, e.g. when walking or taking it around the farm. Sensing results for PUs fetched for the current location are not getting invalid because of its low mobility. GPS or cellular positioning system can be used for keeping track of mobile user. The geo-location from BS is well known.

4.1.3 Mid/Long Range: High Mobility

In this case, sensing results for PUs fetched from the current location are getting invalid because of fast mobility of the user, e.g. in a vehicle. The geo-location from BS is well known. More attention is needed for exploiting TVWS as it sets high constraints on PU sensing.

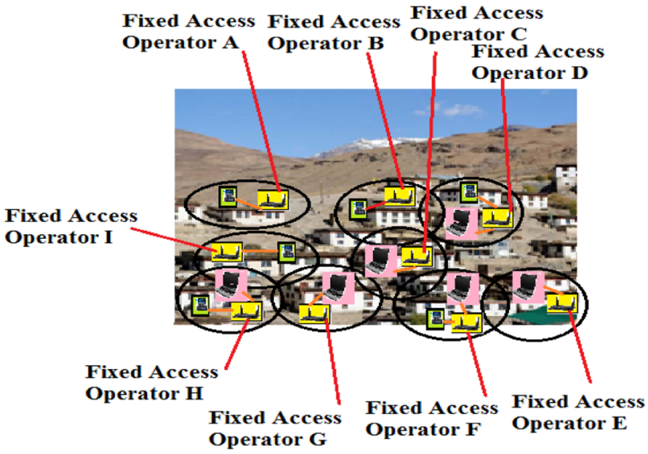

Figure 4 Uncoordinated networks, short range (villages in Maharashtra, India).

4.1.4 Centralized Network Management

In this case, we considered a network centric solution for allocating available TVWS for the user terminal to get connectivity. The available TVWS is considered based on location rather than on time. In rural India, TVWS would be largely available and in time. Once the terminal accesses the network, it can be left under the control of the network. For instance high layer signaling can be utilized for this purpose, e.g. handover command to hand-off to a new frequency or system broadcast messages can be used to notify terminals about change of the frequency.

4.2 Use Case: Short Range Wireless Access

Internet access is provided by BS to the end user by exploring TVWS over the ranges similar to the cellular system 0 to 50 m [15]. This use case is further studied in the next sections.

4.2.1 Uncoordinated Networks

In rural areas, the houses are large. All residents are equiped with their own Access Points (AP) operating in the WS frequency band. Thus, multiple coordinated networks can be an appropriate choice (see Figure 4). This scenario is also useful for surfing at the time of farming, diagnosis, in animal husbandry, etc.

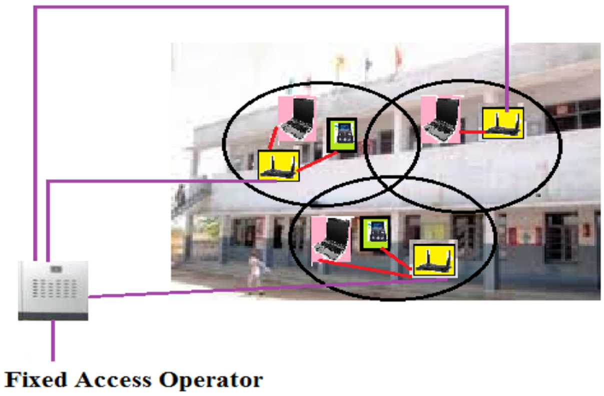

Figure 5 Coordinated networks, short range, and Fixed Access operator (schools, Gram panchayat or Tahasildar offices).

4.2.2 Coordinated Networks

WS networks in the close proximity are operated in a coordinated manner by the WS operator (see Figure 5). Examples of this kind of usage can be academic institute, the Gram Panchayat offices (i.e. local self-governments at the village which is responsible for overall village administration like looking after public health, education, keeping records of births/deaths, land details, etc.) or Tahasildar offices (i.e. head of Taluka administrations responsible for regulating the functionality of Gram Panchayat office, responsible for emergency services like natural calamity case such as lightening death, affected due to flood, etc., responsible for revenue collection such as rehabilitation/petitions/land reforms/enactment of various legislations and all other technical functions).

4.3 Hybrid of Uncoordinated and Coordinated Networks

Overall deployment can be thought of as a combination of both uncoordinated and coordinated networks. Such situation could be the case in government general hospital (primary health centre), in veterinary hospital and house for older people. In order to work properly, effective coexistence methods need to be in place for this scenario.

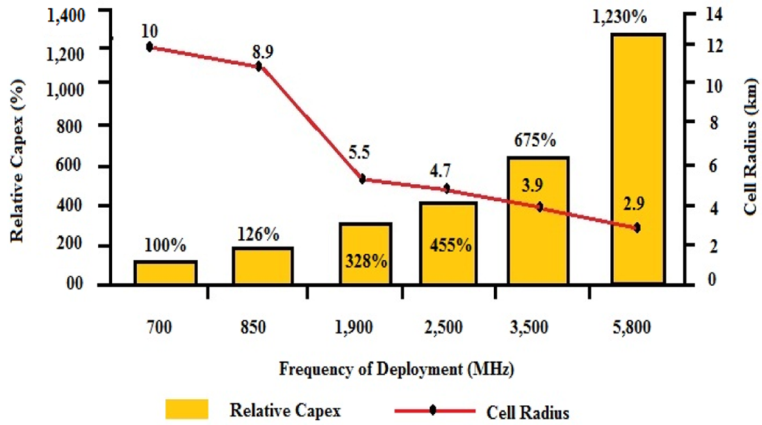

Figure 6 Relative capex vs. frequency of deployment vs. cell radius [17].

4.4 Use Case: Opportunistic Spectrum Access to TVWS by Cellular Systems in Absence of PU

In this case, TVWS slots are available sporadically for SUs such as for, e.g., multi-mode user terminals being able to operate as, among other systems, cellular systems in licensed and unlicensed spectrum. The supported unlicensed spectrum is assumed to include TVWS, i.e 470–806 MHz in India.

The cellular system in this band provides the following advantages:

- *Lighter infrastructure*: due to improved propagation characteristics in the TVWS bands compared to typical license band (GSM 1800 MHz, 2.1 GHz or 2.5 GHz bands for 3G/broadband wireless access,a larger cell size is chosen which will lead to lighter infrastructure and will result in reduced capital expenditure (CAPEX) (see Figure 6). Of course, in this case deployment in rural or high-cost regions becomes economically viable.
- Two or three times as many less sites required for initial coverage at 700 MHz compared to 2.1 or 2.5 GHz. An LTE network at 700 MHz would be 70% cheaper to deploy than an LTE network at 2.1 GHz-GSMA.

Selecting 700 MHz band for various application will saves the relative capital expenditure by two or three times as many less sites required for initial coverage at 700 MHz compared to 2.1 or 2.5 GHz (see Figure 7).

Table 4 Comparative study of cost vs propagation at frequency [17].

Cost	Propagation at frequency		
	700 MHz	1900 MHz	2400 MHz
Total Network cost @150K/cell	$150,000	$600,000	$1,500,000
Network Cost per Customer	$180	$725	$1820
# Mos. to Network Cost Break-even	9 months	36 months	91 months

Figure 7 Cell site coverage per thousand square miles (1000 sq. miles = 1609.34 km) [17].

- *Increased spectral efficiency* through reduced propagation loss (see Figure 8). A possible deployment choice is to keep a cell size as it is. The case of licensed band deployment leads to:
    1. Higher Quality-of-Service (QoS) achieved in a given cell. But these propagation characteristic may cause the interference issues which require an adequate handling like power management, suitable frequency re-use factor for TVWS.
    2. Higher QoS within a given cell at lower RBS/mobile devices (MDs) output power level. The inherent power consumption can be reduced.
    3. The hybrid solution of combination A and B is possible, i.e, a moderate reduction in RBS output power levels combined with a moderate improvement of the QoS.
    4. Increased spectral efficiency through extended macro diversity. A possible deployment choice is to keep cell size as it is the case of licensed band deployment. Then, joint operation of neighbouring RBS can be explored in order to achieve a higher macro-diversity gain in UL (multiple RBS are decoding jointly the received signals) or in the DL (multiple RBS are contributing to jointly optimized transmission).

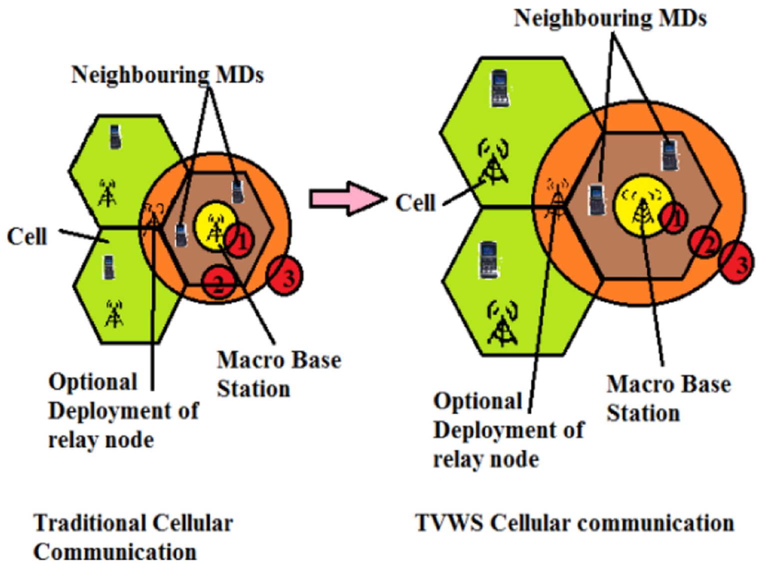

Figure 8 Improved coverage and reduced propagation loss in TVWS (note: symbols 1, 2 and 3 indicate decreasing throughput level, QoS, etc.).

4.5 Use Case: Ad-hoc Networking over White Space Frequency Bands

In this case, user devices and other devices like APs communicate with each other to share information or to run joint applications or services, or to execute other similar tasks. The communication happens by forming an ad-hoc network operating in WS frequency band. There can be two or more devices in the ad-hoc network formed like device-to-device connectivity (video communication in the case of NADR system) and ad-hoc networking (e-health; the devices can be operating a localized social networking service).

5 QoS in TVWS Cognitive Access

One of the challenging features of the TVWS is its variation across space and time. More specifically the available channels are not contiguous and vary from one location to another. In addition the white space available in a given location can vary with time if one or more of the TV band Pus start/stop operation. Opportunistic access to TVWS is interruptible in the sense that CR has to cease transmission immediately and relocate to a new band as soon as

Table 5 Technical characterstics for PMSE.

Applications	RF output	Max. RF Bandwidth (KHz)	Transmission height
PWMs	30 mw	200	1.5 to 12 m
Talkback	30 mw	20–50	1.5 to 12 m

the DVB-T or PMSE which is already using white space on secondary basis; appears. The delay associated with such relocations may face cognitive users with abrupt QoS degradation as communication peers need to coordinate the frequency transition, and many parameters across the protocol stack have to be reset to match the characteristics of the new frequency band. Therefore, cognitive radio links built on TVWS are inherently unreliable. The issue is on how to provide the best quality TVWS for secondary usage to maximize persistence of allocations while avoiding interference with primary users.

The QoS requirements for PMSE are given below.

5.1 High QoS

The wireless microphones and remote controls (e.g. fireworks) need a high reliable radio link interface else would cause degradation in quality of the production. The maximum tolerable delay 1min with required bandwidth of several of 100 KHz.

5.2 Moderate QoS

The equipment can have a certain probability of interference and can tolerate certain interference than mobile speech services. These devices are used for speech which is not intended for broadcasting. The required bandwidth of 20–50 KHz is sufficient with tolerable delay not more than 1 min.

6 Regulatory Activities Related to CR and TVWS

On the regulatory field, presently no specific regulation has been made for CR technology in India. In our views CR devices may be permitted to bands in which spectrum activity is low, location of base stations are known and receivers are robust against interference. Possible Indian approaches operating secondary TVWS need to be analyzed by national regulators WPC. Researchers must focus to the development of IEEE 802.11af and to the assessment of three cognitive techniques, like spectrum sensing [17–22], geo-location database and beacon, in order to provide protection to the licensed radio services.

Geo-location capability must be present in all fixed devices, with an accuracy of +/- 50 m. This position information is used to query a database for a list of available TV channels that can be used for cognitive devices operation. The database will include the information of all TV signals and may also have information on wireless microphone usage because of the challenging signal detection in low power wireless microphones. The following aspects have to be considered:

- Protection of digital broadcasting services including mobile TV.
- Protection of fixed and mobile services in the frequency bands of 470–520 and 520–585 MHz.
- Protection of services adjacent to a 470–806 MHz band like protection of mobile satellite services and broadcasting except aeronautical mobile satellite (R) service in the frequency band of 806–890 MHz and protection of IMT applications in the frequency band of 450.5-457.5 MHz paired with 460.5–467.5 MHz.
- Protection of PPDR communications.
- Definition of the requirements for the geo-location database approach.

As per [23–26], the regulation requirements for the IEEE 802.11af standard based on CR utilizing TVWS are as shown in Table 6. The exact regulatory framework of CR technology utilizing TVWS frequency band is yet to be finalized to guarantee an efficient exploitation of frequency bands in TVWS. As more research went along, it came clearer that the geo-location will play the main role of defining the channels that must be free of wireless sensing device transmissions. Hopefully the spectrum management and resource management of CR technology contain all the regulation constraints for all of the TVWS opportunities and that additional information will be taken from the network in order to exploit this portfolio to allocate the spectrum access using QoS based rules.

7 Conclusions

This paper has given the overview of DD scenarios and most promising applications for exploiting TVWS in Indian scenarios. The TVWS is expected to be available for the secondary spectrum access, especially in rural India. The applications like e-governance-education-agriculture-health-animal husbandry can take the benefits for improving Gross Domestic Product. Further,

Table 6 Regulation requirements for IEEE 802.11af.

Parameter	[23]	[24]	[25]	[26]
Quantized signal energy				
TV signals (8 MHz)	Not required	–114 dBm	Not required	Not required
Wireless microphone	Not required	–126 dBm in 200 kHz	Not required	Not required
Geo-Location accuracy	50 m	100 m	–	Not specified
Transmit power (fixed) EIRP	1 W (with max 6 dBi antenna gain)	100 mW	–	Local Specific
Transmit power (portable) EIRP	100 mW	100 mW	–	Local Specific
Transmit power in adjacent band to DTT signals	40 mW	20 mW	–	Local Specific
Out of band radiation	–55 dBm under the inband level	–	–	
Time between sensing	1 min	1 sec		

the use cases based on users and BS geo-location, as well as user's mobility, have been discussed based on Indian scenario showing that both cellular and short range applications can exploit TVWS. The QoS in CR exploiting TVWS has been discussed. Finally, assessment of regulatory framework is given to prevent harmful interference to licensed users. However, it does not provide insights to operate the available spectrum efficiently. Current research initiatives are tackling this objective.

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Biographies

Tanuja Satish Dhope (Shendkar) graduated Electronics and Telecommunication Engineering at the Cummins College of Engineering, University of Pune, in 1999. She received her Master in Elecronics Engineering from Walchand College, Sangli, Shivaji University in 2007. Currently she is pursuing her Ph.D. in wireless communication at the University of Zagreb, Croatia. Her research focus is on cognitive radio network optimization with spectrum sensing algorithms, radio channel modelling for cognitive radio, cooperative spectrum sensing, Direction of Arrival (DoA) Estimation algorithms in Cognitive Radio and in SDMA. She has published several scientific papers in journals and conference proceedings.

Dina Simunic is a full professor at the University of Zagreb, Faculty of Electrical Engineering and Computing in Zagreb, Croatia. She graduated in 1995 from the University of Technology in Graz, Austria. In 1997 she was a visiting professor in Wandel & Goltermann Research Laboratory in Germany, as well as in Motorola Inc., Florida Corporate Electromagnetics Laboratory, USA, where she worked on measurement techniques, later on applied in IEEE Standard. In 2003 she was a collaborator of USA FDA on scientific project of medical interference. Dr. Simunic is a IEEE Senior Member, and acts as a reviewer of *IEEE Transactions on Microwave Theory and Techniques*, *Biomedical Engineering and Bioelectromagnetics*, *JOSE*, and as a reviewer of many papers on various scientific conferences (e.g., IEEE on Electromagnetic Compatibility). She was a reviewer of Belgian and Dutch Government scientific projects, of the EU FP programs, as well as of COST-ICT and COST-TDP actions. She is author or co-author of approximately 100 publications in various journals and books, as well as her student text for wireless communications, entitled: *Microwave Communications Basics*. She is co-editor of the book *Towards Green ICT*, published in 2010. She is also editor-in-chief of the *Journal of Green Engineering*. Her research work comprises electromagnetic fields dosimetry, wireless communications theory and its various applications (e.g., in intelligent transport systems, body area networks, crisis management, security, green communications). She serves as Chair of the "Standards in Telecommunications" at Croatian Standardization Institute. She servers as a member of the core group of Erasmus Mundus "Mobility for Life".

Ramjee Prasad (R) is a distinguished educator and researcher in the field of wireless information and multimedia communications. Since June 1999, Professor Prasad has been with Aalborg University (Denmark), where currently he is Director of Center for Teleinfrastruktur (CTIF, www.ctif.aau.dk), and holds the chair of wireless information and multimedia communications. He is coordinator of European Commission Sixth Framework Integrated Project MAGNET (My personal Adaptive Global NET) Beyond. He was involved in the European ACTS project FRAMES (Future Radio Wideband Multiple Access Systems) as a Delft University of Technology (the Netherlands) project leader. He is a project leader of several international, industrially funded projects. He has published over 500 technical papers, contributed to several books, and has authored, coauthored, and edited over 30 books. He has supervised over 50 PhDs and 15 PhDs are at the moment working with him. He has served as a member of the advisory and program committees of several IEEE international conferences. In addition, Professor Prasad is the coordinating editor and editor-in-chief of the Springer International Journal on *Wireless Personal Communications* and a member of the editorial board of other international journals. Professor Prasad is also the founding chairman of the European Center of Excellence in Telecommunications, known as HERMES, and now he is the Honorary Chair. He has received several international awards; the latest being the "Telenor Nordic 2005 Research Prize". He is a fellow of IET, a fellow of IETE, a senior member of IEEE, a member of The Netherlands Electronics and Radio Society (NERG), and a member of IDA (Engineering Society in Denmark). Professor Prasad is advisor to several multinational companies. In November 2010, Ramjee Prasad received knighthood from the Queen of Denmark, the title conferred on him is Riddere af Dannebrog.