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TV White Spaces: Challenges for Better Managing Inefficiencies

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Abstract- TV White Spaces refers the unoccupied portions of spectrum in the UHF/VHF terrestrial television frequency bands. Operation on the trial and test are currently underway in various countries and some commercial applications are emerging, looking at improving the utilization. The concept of sharing the highly valued UHF spectrum resource and its use with the primary terrestrial television service is a primary concern today. Wireless broad-band applications are the main focus of trials, nonetheless, the usefulness of this highly sought after spectrum is also being considered for other applications, such as machine-to-machine communications (M2M). This paper reviews relevant regulatory aspects concerning the operational implementation of Television White Space (TVWS) devices in some parts of the spectrum allocated to TV broadcasting. Also the paper overviews the different approaches and considerations currently being reviewed for TV white spaces. These approaches are intended for improving the efficiency of the spectrum resource use, through accessing idle spectrum to deliver low-cost implementation and rapid development of user applications.

Index Terms- Television White Space (TVWS), TV Band Devices (TVBD), very high frequency (VHF), ultra high frequency (UHF)

I. Introduction

The term "whitespace" refers to portions of licensed radio spectrum that licenses do not use all the time or in all geographical locations. Several regulating bodies around the worlds are moving towards allowing unlicensed access to these frequencies, subject to the proviso that licensed transmissions are not adversely affected.

Recently the Federal Communications Commission (FCC) in the United States issued a report which permits cognitive use of the TV white space spectrum. Originally White Space is the term used by the FCC for unused TV spectrum. The new formulated rules open up an opportunity to develop new wireless networks to utilize the spectrum. This VHF/UHF spectrum provides superior propagation and building penetration compared to other unlicensed spectrum in other bands like 2.4 and 5 GHz bands. However, access to this new spectrum also comes with some technical challenges. The FCC rules specify a number of requirements on these cognitive wireless network.

The frequency allocation process creates the band plan. White space is assigned between the radio bands or channels to avoid the interference. In this case, while the frequencies are unused, they have been specifically assigned for a purpose, such as guard band. These white spaces exist naturally between actively used channels but assigning nearby transmissions to immediately adjacent channels will cause destructive interference to both. In addition there is also unused radio spectrum which has either never been used, or is becoming free as a result of technical changes. In particular, the switchover to digital television frees up large areas between about 50 MHz and 700 MHz. This is because digital transmissions can be packed into adjacent channels, This means that the band can be compressed into fewer channels, while still allowing for more transmissions.

TV White Spaces (TVWS) are frequencies made available for unlicensed use at locations where the spectrum is not being used by licensed services, such as television broadcasting. Some of this spectrum may be licensed for other uses in the normal way- for example in the UK, the old TV channels 61-69 (798-862 MHz) have been assigned for the LTE mobile use. The spectrum is located in the VHF (54-216 MHz) and UHF (470-698 MHz) bands, in the US, and has characteristics that make it highly desirable for wireless communications [1][4][8][14].

II. Operation Authorization and rules

The TV Band Devices must communicate with a database to obtain a list of currently available white space channels to utilize the unlicensed spectrum band and ensure incumbent users. The available channels may vary, depending on TVBD device type and location.

The authorized white space manager requests for the radio. The white space manager automatically provides available channel data in accordance with a set of rules, such as those defined by the FCC, or Ofcom. The most significant requirement is to avoid areas where protected entities such as TV stations operate. After a radio receives a channel map, final channel selections are made by the radio. This decision is based on rules, radio technology and the offered channel map. This "common sense approach" to unlicensed spectrum provides remarkable benefits for the industry. Spectrum Bridge, Inc. (SBI) is recognized as a global leader in the TV White Space ecosystem and was certified as the first TVWS Database Administrator in the United States (FCC) and United Kingdom (Ofcom). SBI has developed numerous products and solutions for the TVWS industry based on our patented intellectual property [3][7][8][14].

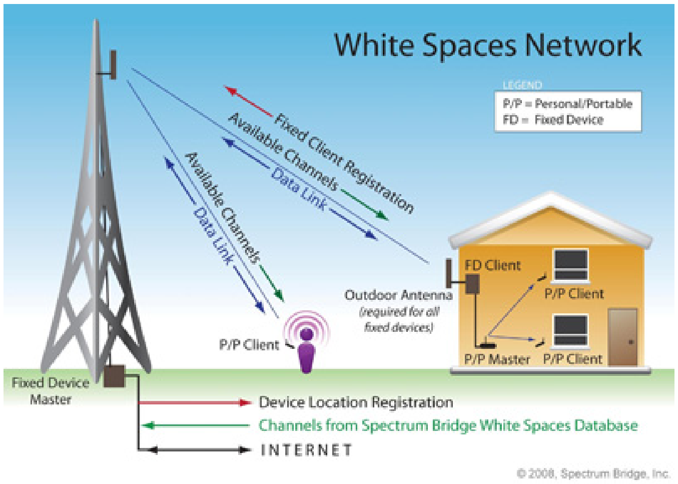

Fig. 1: General overview of White space Network

Network Operators

To empower the White Space ecosystem the Spectrum Bridge offers a variety of solutions. As more devices are deployed in unlicensed bands, network operators need solutions to manage and optimize the performance of wireless networks. This White Space plus solution addresses this need and will ensure the network operates at peak performance. The solution offers guided channel selection and real-time interference alerts to equip the network with the best available channels available and mitigate interference.

Devise Authorization

It is necessary and appropriate to authorize the use of WSDs in the UHF TV band through license exemption. It is to confirm the use of devices on licensed exempt basis would not lead to harmful interference to other spectrum users. It also guarantee that there is no adverse impact on technical quality of service provided by that devices and operate under the control of a geo-location database qualified by Ofcom in UK and FCC in US.

Generally, license exemption method suppress the regulatory and administrative burden compared to other forms of authorization, such as individual licenses. There may be a wide use of White Space technology such the applications for TVWS. The industry would lead to proposed a mass market consumer use of devices and deployments of a very large number of devices (for example for machine to machine applications). It can be considered that authorization on license exempt basis would likely to remove barriers to access to the spectrum, foster innovation and competition in the development of WSDs, and thereby result in benefits to consumers.

FCC Rules

A number of the requirements to operate in TV white space are based on cognitive radio technology including location awareness and spectrum sensing. Also there are other requirements that intended to provide protection for the licensed services that operate in the TV bands. These devices operating in TV white space spectrum impose some technical challenges for the design.

The devices which operate according to the TV Whitespace rules are referred as TV band devices (TVBDs) by the FCC. TVBDs can be categorized in to two classes: fixed and portable/personal. The portable devices are further divided into Mode I and Mode II devices. Fixed devices are permitted to transmit up to 30 dBm (1 watt) with up to 6 dBi antenna gain, while portable devices are permitted to transmit up to 20 dBm (100 mw) with no antenna gain. Fixed devices are permitted to use a higher gain antenna as long as the transmit power is decreased dB-for-dB for any antenna gain above 6 dBi. The TV channels include the very high frequency (VHF) channels 2-13 and the ultra high frequency (UHF) channels 14-51. However, there are restrictions on which channels are permissible for use by TVBDs. Fixed devices are permitted in the VHF channels except channels 3-4 and on the UHF channels except channels 36-38. Portable devices are restricted in the VHF band. Portable devices are permitted on the UHF channels except 14-20 and channel 37. The exclusion for channels 3-4 is to prevent interference with external devices (exaple DVD players) which are often connected to a TV utilizing either channel 3 or 4. Portable devices are not permitted on channels 14-20 since in some areas Television broadcast signals are protected with a protection contour. The FCC defined that TVBDs must operate outside the protected contour because within the protected contour there are special rules for operation on a TV channel adjacent to the TV broadcast channel. Fixed TVBDs are not permitted to operate on channels adjacent to the TV broadcast channel. Portable devices are permitted to operate on an adjacent TV channel; however, when operating on an adjacent TV channel, the maximum allowed transmission power is 16 dBm (4 dB lower than on non-adjacent channels) [14][25].

Networking Issues

Whenever a network of TVBDs is formed for proper functioning than issues of spectrum sensing arise. Collaborative sensing, one of issue is recently being highlighted. This sensing seeks to apply ideas from distributed detection and data fusion to jointly process the spectrum sensing statistics from multiple TVBDs. The inherent diversity stemming from distributed observations, when exploited leads to more efficient spectrum sensing schemes compared with single-node sensing.

Network quieting protocol can be one of the possible way of handling the above mentioned issue which mandates all the TVBDs in a geographic area to turn off simultaneously, so as to "quiet" the TV channel for a certain period of time to sense the TV/wireless microphone signals. This concept is similar to request-to-send/clear-to-send (RTS/CTS) mechanism in 802.11 networks, whereas the RTS/CTS is used to avoid interference-induced collision during transmission. The acceptable interference power level (power received by TVBDs) for reliable spectrum sensing may need to be even lower than the noise floor, so the cleared geographic area provided by RTS/CTS may not be large enough to detect and receive the signal required for the operation [14][16][25].

III. COEXISTENCE APPROACH

The Fig.2 shows the users in the UHF TV band and in adjacent frequency bands with which WSD devices will coexist for its operation.

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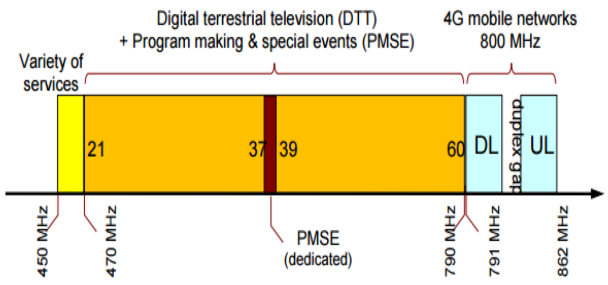

Fig. 2: General overview of existing frequency approach

Based on the Ofcom, this band of frequency is currently used for DTT broadcasts by PMSE. PMSE use permitted indoor pass throughout the band, subject to licensing, and outdoor use in order to avoid harmful interference to DTT users. The spectrum immediately above 790 MHz is used by 4G mobile services. The spectrum immediately below 470 MHz is used by a variety of services including business radio, scanning telemetry, short range devices, maritime, Prison Service, and Revenue and Customs. All of these uses must be protected from harmful interference to/from WSDs, and all of these which has different characteristics that must be taken into consideration. In managing coexistence between WSDs and existing users, It is necessary to seek to ensure that there is a low probability of harmful interference to DTT, PMSE services in adjacent bands. This can be obtained via the calculation of the maximum allowed power at which a WSD can transmit in each frequency, along with the accounting of other spectrum users.

Recently FCC issued the regulatory rules for cognitive radio use on TV white space spectrum. These new rules along with the number of challenges provides the valid opportunity. The challenges require development of cognitive radio technologies like spectrum sensing as well as new wireless PHY and MAC layer designs. These challenges include spectrum sensing of both TV signals and wireless microphone signals, frequency agile operation, geo-location, stringent spectral mask requirements, and the ability to provide reliable service in unlicensed and dynamically changing spectrum [14][25].

IV. WHITE SPACES IDENTIFICATION AND INTERFERENCE AVOIDANCE

TVWS which refers to frequencies allocated for TV broadcasting service but not used locally. TV White Space Spectrum Systems (TVWSSS) are recently in practice for realizing the Dynamic Spectrum Access concept which can be a promising solution. Generally there are three methods of identifying White spaces: spectrum sensing, pilot channel (beacon) and geo-location database. These can be used independently or in combination. These operation may be considered as "third-rate" status (after the primary and secondary services) of the CRS opportunistic services. The CRS have to protect other radio services working in the adjacent and same geographic areas, also in same and adjacent frequency bands, which implies establishing criteria and mechanisms allowing full protection of all incumbents. The protection mechanism can be obtained when compatibility criteria are known, and current and planned spectrum usage is controlled.

Spectrum sensing

Spectrum sensing is a natural solution for learning about the existence of other incumbent radio services and controlling the device emission parameters by the CRS devices. It means that the CRS devices continuously detects current spectrum usage and takes information about the current spectrum situation. However such solution is still under research. First of all there is "hidden node" problem - where the sensing device is hidden and cannot sense primary signals, it may hide due to obstruction (like buildings, hills etc.) on the receiving path. In such situation it can declare "free spectrum" when in reality it is occupied. Practically it is impossible to implement in some frequency bands (such as TV UHF band) which try to increase the accuracy of the sensing level and solve the hidden node problem with a single device that lead to the situation where the required sensing level is very low. Also in case of very short time transmissions (burst, PMSE, M2M etc.) where the device is active for very short time period, it is difficult to detect the transmission and avoid interference. Some improvement is offered by Cooperative Sensing (CS), where many devices together are sensing the spectrum and exchanging the information that they collect. This may solve the problem of the hidden node, however, it is more complicated solution which cannot be used without recurring to additional protection mechanism. Also this does not work in protecting the receive-only services, such as radio astronomy[10][24].

Pilot channel (beacon)

One of possible solutions for protection of the incumbents is the pilot channel (beacon). Here a dedicated channel is used to inform every WS device about the current spectrum usage and free channels available. But it is difficult to end a common regional-wide frequency allocation for such special pilot channel due to different frequency allocations in different countries. However separate channel can be allocated for separate country but in that case many frequency pilot bands around the World can complicate the wireless mass market. Also interference problems arise between stations transmitted beacons in different regions which needs to be mitigated. Such solution has met with limited success so far, since alternatives seem to be more promising. However if some operators may use their own transmission channels (e.g. GSM or Wireless Internet operators) - the information on the available spectrum can be sent via a conventional GSM/UMTS/LTE channel or via ISM/RLAN band.

Geo- location databases

Geo-location database is considered as the most promising solution because it can be used as one simple solution for solving all problems (protection of reception-only devices, hidden node problem, sensing level etc.) for all types of transmissions and frequency ranges. Every regulatory radio systems has to be registered in the database along with rules that will determine the White Space Spectrum availability. The WS device has only to determine its location (using GPS), send its geographical coordinates to the database and asks it which channels are available under specific conditions (transmit power, antenna height, mode of operation, etc.). Data in the database can be easily changed, which offers additional flexibility of spectrum usage and protection of incumbents. The database can also include "safe harbor" channels for special applications, e.g. Program Making and Special Events (PMSE) channels, which may be reserved for local PMSE and be forbidden for CRS. Additional spectrum related operations can be performed with on-line real time access to the database. Such operation is necessary to assure, for instance, protection of the WS CR devices that just have channels access for a limited time [14].

V. RF Architecture Challenges

Variation across the Space and time is one of the challenging features of the white space. Specifically the available channels are not contiguous and vary from one location to another. Also the white space available in a given location can vary with time and frequency of TV band primary users start/stop operation. This requires frequency agile architectures to map to the available white space spectrum, retune to a new operating channel, or tune-away to perform sensing measurements. The requirements are more complex such as frequency division duplex (FDD) networks which needs two separate channels for operation. The RF challenges that need to be solved using FDD networks includes independent tuning of transmitter and receiver, providing RF isolation (in the order of 50dB) between transmitter and receiver. Using variable transmitter and receiver frequency develops highly linear receivers over a wide dynamic range to handle in-band high power TV broadcasts.

The possible approaches to implement the RF front end for the frequency agile transceiver are: duplexers, switching RF filter banks, and tunable filters. Here the white space availability may change according to the duplexing method used such as time division duplexing (TDD) or frequency division duplexing (FDD). In addition to this different FDD RF architectures can result in different white space availability. The following present the white space availability for analyzing the availability metrics

- Maximum number of independent networks that can utilize the white space without acquiring co-channel sharing.
- The minimum number of TV channels occupied by other networks before co-channel sharing is made. The randomness here is generated by assuming that any channel of the white space can be lost with equal probability.

To increase efficiency and to reduce the burden on regulators for spectrum management the dynamic spectrum-use model can be applied. The few research on TVWS trials have proved that very large portions of the allocated spectrum bands are not actually in use, and this has thrown into question the whole premise of ‘spectrum scarcity’, upon which current allocation models are based. Hopefully, as more on the ground spectrum-use information becomes available from more developing countries, and from more sources than just the national ICT regulator, such as through crowd sourcing, there will be better awareness of the increased potential of the radio spectrum resource.

The history of TVWS support in the US where NGOs first pushed for its use, civil society has an important role to play in bringing attention to dynamic spectrum use. With a technology-neutral agenda, civil society groups are not biased toward a particular access solution and can be a trusted partner in helping to guide the adoption of the most effective mix of technologies.

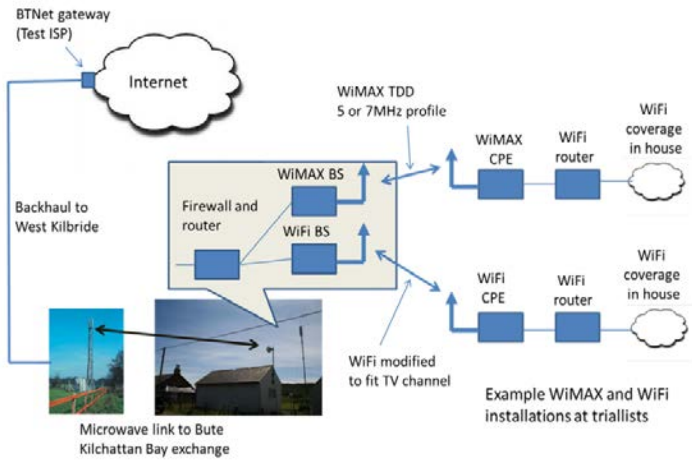

Fig 3: Architecture design of TV whitespace

Spectrum Sharing and interference management

It is required to effectively utilize the available spectrum with the reliable communication which also satisfy the FCC rules required for cognitive operation in the TV band. One of the major challenges that face reliable operation in the white space is interference among peer TVBDs given the unlicensed nature of operation in this band. Managing interference between nodes in the same network is generally a difficult problem, and the problem becomes more challenging when these TVBDs belong to heterogeneous networks using different air interfaces. Spectrum sharing techniques can be divided into three main categories as follows.

1) Non-cooperative techniques
2) Rule-based techniques
3) Message-based techniques

1) Non-cooperative Techniques: In non-cooperative spectrum sharing techniques each system tries to maximize its own utilization of the spectrum while mitigating the effects of interference from other networks. Examples for non-cooperative techniques include

- Dynamic frequency selection (DFS) in which nodes select channels with least interference.
- Multichannel-DFS (M-DFS): The access-point can select a subset of the available channels to minimize the overall outage probability and improve system throughput. DFS is a special case of M-DFS when the access-point is restricted to use one channel.
- Interference cancellation via multiple antenna receivers. If the receiver is equipped with multiple-antennas, interference cancellation algorithms can be utilized. For example, an MMSE receiver can help canceling the incoming interference signal through estimating the

interference covariance matrix and nulling out the dominant interference signal.

2) Rule-based Techniques: In rule-based techniques the TVBDs agree on a set of rules to implement, and do not use a control channel to exchange information. Although there is no explicit coordination between the nodes, the set of rules should be designed to ensure fairness, efficiency and interference avoidance. Examples for rule-based techniques are listen-before-talk and transmit power control.

3) Message-based Techniques: In message-based sharing techniques, the TVBDs operating in the unlicensed band exchange messages (over-the-air or backhaul) to enable efficient and fair spectrum sharing and limit the interference among them. A message-based sharing technique should specify how to implement the control channel required for coexistence.

Quality of white space channels

When the co-existence between WSDs and DTT is considered, much of the attention is focused on the extent to which the transmissions of WSDs might affect DTT reception. Also the potential users of white space spectrum are likely to be interested in the extent to which DTT signals from TV transmitters might impinge upon white space channels that are available for use in a particular location. (When a WSD is given permission to use a white space channel in a particular location, there is no guarantee that the channel will be free of DTT signals that could potentially interfere with the white space transmissions.) From the numerous DTT signal strength measurements that were taken across Bute*, estimates of white space channel availability were made for each test location, and the residual DTT signal strength in each of those channels was calculated. This gives a rough indication of the quality of each white space channel at each test location. Fig. 4 shows the resulting Cumulative Distribution Function (CDF), from which it can be seen that at least 75% of locations have a residual DTT.

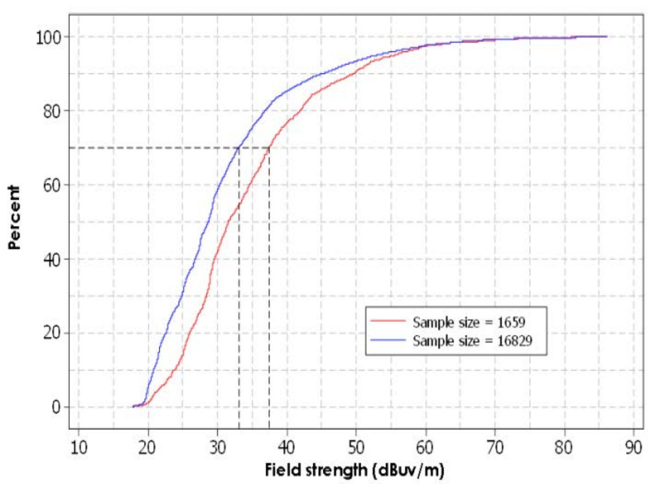

Fig 4: Comparison of DTT and WSD measured on Bute

White space a paradigm shift

A new option which is emerged in the spectrum access is the use of the "white space" spectrum - the unused portions of the spectrum band in and around TV transmissions. White space meets all of the requirements for M2M communications. It is unlicensed and so access to it is free. It is plentiful with estimates of around 150MHz of spectrum available in most locations - more than the entire 3G cellular frequency band. It is globally harmonized since the same band is used for TV transmissions around the world. Finally, it is in a low frequency band which enables excellent propagation without needing inconveniently large antenna sin the devices. This is why white space is the paradigm shift. Access to white space provides the key input needed to make the deployment of a wide-area machine network economically feasible. It is clear that white space access will require devices that have the following characteristics:

1. Relatively low output power: The FCC has specified 4W EIRP for base stations and 100 mW EIRP for terminals. These are orders of magnitude lower than cellular technologies.
2. Stringent adjacent channel emissions: White space devices must not interfere with existing users of the spectrum, predominantly TVs. Hence, the energy that they transmit must remain almost entirely within the channels they are allowed to use. The FCC has specified that adjacent channel emission need to be 55 dB lower than in-band emission, a specification much tighter than most of today's wireless technologies.
3. The need to frequently consult a database to gain channel allocation. Devices may need to rapidly vacate a channel if it is needed by a licensed user. They must consult a database to be informed as to the channels they can use and must quickly move of these channels as required.

Interference can be problematic in white space. Many channels have residual signals from TV transmissions. These can either be in-band emissions from distant, powerful TV masts that are too weak for useful TV reception but still significantly above the noise. Alternatively, they can be adjacent channel emissions from nearby TV transmitters some of which are transmitting in excess of 100 kW. In addition, since the band is unlicensed, other users might deploy equipment and transmit on the same channels as the machine network, causing local interference problems. These are not insurmountable issues. But no current technology has been designed to operate in such an environment and so would be sub-optimal at best. For example, It can be shown that in the UK an optimized technology could access around 90 MHz of white space other all the interference issues are taken into account, whereas an existing technology such as Wi-Fi or Wi-MAX could only access around 20 MHz So white space spectrum provides the key to unlock the machine network problem. But it comes at the cost of needing to design a new standard. Fortunately, that new standard has been developed. It is called Weightless [4][14][16][25][26][30].

VI. Conclusion

The newly designed rules which allows the use of the TV white space spectrum which is one of the key drivers in the development of dynamic spectrum access. It fosters the revolutionary era in wireless applications and drives the novel technical solutions of unused wide band of frequencies. From this paper it can be seem that, many of the technical challenges are unconventional and interdisciplinary in nature. For example, the development of spectrum sensing techniques involves RF design, robust signal processing, pattern recognition, networking protocols, etc. The choice of RF architecture is no longer merely a hardware issue, but will directly affect the upper layer performance. To meet the stringent spectral mask requirements, novel signal processing designs such as transmit pre-coding and receive equalization become possibly indispensable tools. Spectrum sharing raises new challenges in applying techniques from information theory to heterogeneous networks. It can be expected that recognizing those challenges will lead to a fruitful interaction among academia, industry, and policy makers, and finally lead to the success of cognitive radio in the TV white space spectrum.

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