International Telecommunication Union

# ITU-R

Radiocommunication Sector of ITU

**Report ITU-R SM.2405-1**
**(12/2020)**

# Spectrum management principles, challenges and issues related to dynamic access to frequency bands by means of radio systems employing cognitive capabilities

**SM Series**

**Spectrum management**

International Telecommunication Union

## Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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| Series | Title |
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| **F** | Fixed service |
| **M** | Mobile, radiodetermination, amateur and related satellite services |
| **P** | Radiowave propagation |
| **RA** | Radio astronomy |
| **RS** | Remote sensing systems |
| **S** | Fixed-satellite service |
| **SA** | Space applications and meteorology |
| **SF** | Frequency sharing and coordination between fixed-satellite and fixed service systems |
| **SM** | **Spectrum management** |

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# REPORT ITU-R SM.2405-1

## Spectrum management principles, challenges and issues related to dynamic access to frequency bands by means of radio systems employing cognitive capabilities

(2017-2020)

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**Scope**

This Report addresses possible techniques in spectrum engineering and spectrum management principles, challenges and related issues which may facilitate dynamic access to spectrum by means of radio systems employing cognitive radio systems (CRS) capabilities. The focus of this Report is to study general framework of dynamic spectrum access techniques employing CRS capabilities and describe some of the challenges and issues related to these techniques that have been identified to date. Other than for the use of examples to demonstrate specific issues, any studies aimed at implementing dynamic spectrum access for a specific service operating in a specific frequency band are not within the scope of this Report.

Noting that CRS are more and more presented as an appropriate solution to ensure protection of incumbent services in a specific band in case of dynamic spectrum access, this Report addresses challenges and related issues which are inherent to the upstream process which is under the responsibility of Administrations.

In this Report, developed in response to Resolution ITU-R 58, dynamic spectrum access refers to the use of a portion of spectrum which is not being used at a given time and within a given geographic area, and may be available for use by a radiocommunication application, operating in accordance with the Radio Regulations. In accordance with Resolution ITU-R 58, radio systems employing the principles and techniques described in this Report also need to ensure the protection of incumbent services sharing the same band or operating in the adjacent bands.

## Acronyms and Abbreviations

| | |
|---|---|
| ADC | Analogue to digital converter |
| ACS | Adjacent channel selectivity |
| ARNS | Aeronautical radio navigation service |
| BIH | Botswana Innovation Hub |
| BOCRA | Botswana Communications Regulatory Authority |
| BS | Base station |
| BSS | Broadcasting satellite service |
| *C*/*I* | Carrier to interference |
| CCTV | Closed Circuit TV |
| CEPT | European Conference of Postal and Telecommunications Administrations |
| CPE | Customer premises equipment or customer provided equipment |
| CRS | Cognitive radio systems |
| dB | DeciBel |
| dBd | dB relative to Dipole antenna |
| dBi | dB relative to Isotropic antenna |
| dBm | dB relative to 1 milliwatt |
| dBW | dB relative to 1 Watt |
| DVB-T | Digital video broadcasting – terrestrial |
| DFS | Dynamic frequency selection |
| DSA | Dynamic spectrum access |
| DSAD | Dynamic spectrum access device |
| DTT | Digital terrestrial TV |
| ECC | Electronic Communications Committee (CEPT) |

| | |
|---|---|
| EESS | Earth exploration-satellite service |
| e.i.r.p. | equivalent isotropically radiated power |
| e.r.p. | effective radiated power |
| ETSI | European Telecommunications Standards Institute |
| FSS | Fixed-satellite service |
| GBS | Global broadband solution |
| *I*/*N* | Interference to noise |
| ICT | Information and communication technologies |
| ID | Identification |
| GPS | Global positioning system |
| IEEE | Institute of Electrical and Electronics Engineers |
| IMT | International Mobile Telecommunications |
| IP | Internet protocol |
| LoS | Line of sight |
| LTE | Long-term evolution |
| MIMO | Multiple input and multiple output |
| MSS | Mobile-satellite service |
| NLoS | Non line of sight |
| NRA | National Regulatory Authority |
| P-P | Point to point |
| P-MP | Point to multi point |
| PMSE | Program Making and Special Event |
| SNR | Signal to noise ratio |
| RDSS | Radio determination-satellite service |
| RNSS | Radio navigation-satellite service |
| RR | Radio Regulations (ITU) |
| SRD | Short range device |
| TVBD | TV wide space band device |
| TVWS | TV White Space[*] |
| USAID | U.S. Agency for International Development |
| VHF | Very high frequency (30–300 MHz) |

[*] In the Annexes to this Report on National experiences, reference is made to “white space(s)”. However, in this Report anywhere reference is made to that term, it was replaced by “temporarily unused/unoccupied spectrum”. In order to maintain the original submissions, the term “white space(s)” in the Annex(es) was not replaced by “temporarily unused/unoccupied spectrum” as it reflects the views of the contributing country(ies).

| | |
|---|---|
| VoIP | Voice over Internet Protocol |
| UHF | Ultra high frequency (300–3 000 MHz) |
| W | Watt |
| WAS | Wireless access system |
| WSD | White space device |
| WSDB | White space device database |
| WRC | World Radiocommunication Conference (ITU) |

## 1 Introduction

The growth in demand for additional capacity and spectrum by many different radiocommunication services is resulting in a more challenging spectrum management environment. These challenges often require innovation in spectrum management techniques in order to ensure that services allocated in a frequency band use and share limited spectrum resources efficiently. In certain conditions, the application of dynamic spectrum access may facilitate the efficient use of spectrum. However, use of dynamic spectrum access also introduces new spectrum management challenges. Radio systems employing cognitive capabilities have innovative features which can be used to address these challenges.

This Report discusses general spectrum management principles and spectrum engineering techniques which may be employed to facilitate the dynamic spectrum access by radio systems employing cognitive capabilities. The Report also discusses various issues and considerations which need to be addressed to ensure the use of dynamic spectrum access contributes towards more efficient usage of spectrum, while protecting in band and adjacent band radiocommunication services.

In the context of this Report, temporarily unused/unoccupied spectrum is a portion of spectrum in a band designated for use by one or several applications operating under the provisions of the Radio Regulations and that is not being used at a given time and within a given geographic area. In literature unused/unoccupied spectrum is also denoted as spectrum hole[1].

In the context of this Report, dynamic spectrum access (DSA) stands for the possibility of a radio system implementing CRS capabilities to operate on a temporary unused/unoccupied spectrum and to adapt or cease the use of such spectrum in response to other users of the band.

The identification of the portions of spectrum available for dynamic spectrum access is under the purview of the Administrations and conditions vary on case-by-case basis. It is assumed that these systems applying dynamic spectrum access operate in accordance with the Radio Regulations (RR) and Resolution ITU-R 58. Examples of dynamic spectrum access applications such as use of TV White Spaces and vertical and horizontal spectrum sharing enabled by CRS technologies are reported in the Report ITU-R M.2330. Ability for dynamic spectrum access may be supported via, for instance, capabilities of the device, network element, and/or network external entity (e.g. database).

In consideration of the technical elements contained in this Report relating to TV White Spaces, attention should be paid to the decisions made by WRC-12 and WRC-15 (see No. **5.317A** of the RR).

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[1] R. Tandra *et al.*, “What is a Spectrum Hole and What Does it Take to Recognize One?” *Proceedings of the IEEE*, vol. 97, no. 5, pp. 824–848.

Resolution **235 (WRC-15)**[2] *resolves to invite ITU-R, after the 2019 World Radiocommunication Conference and in time for the 2023 World Radiocommunication Conference* to review the spectrum use and study the spectrum needs of existing services within the frequency band 470-960 MHz in Region 1, in particular the spectrum requirements of the broadcasting and mobile, except aeronautical mobile, services, as well as to carry out sharing and compatibility studies, as appropriate, in the frequency band 470-694 MHz in Region 1 between the broadcasting and mobile, except aeronautical mobile, services, taking into account relevant ITU-R studies, Recommendations and Reports.

## 2 Definition

**Cognitive Radio System (CRS**) (from Report ITU-R SM.2152)

A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained.

## 3 Related ITU-R Recommendations and Reports

The definition of technical and operational requirements for dynamic access to frequency bands by means of radio systems employing cognitive capabilities is highly dependent upon the radiocommunication services to be protected and requires analysis on case-by-case basis.

Applicable ITU-R Recommendations and Reports relating to characteristics and/or protection criteria for different radiocommunication services can be identified with the support from relevant service groups of the ITU-R. Some ITU-R Reports and Recommendation are listed in Annex 3 of this Report for illustration.

Recommendation **76 (WRC-12)** on Deployment and use of cognitive radio systems should also be noted.

## 4 General consideration for the use of dynamic spectrum access employing CRS

### 4.1 Available spectrum resources for the use of dynamic spectrum access employing CRS

The amount of spectrum available for CRSs depends on factors such as the level of protection given to the incumbent services and related applications as well as technical and operational characteristics of CRSs. The amount of available spectrum may depend on the location and vary in time. Availability is significantly reduced if higher CRS powers are employed, particularly in populated areas. Methodology and some examples how to quantify temporarily unused/unoccupied spectrum may be found in the Annexes.

### 4.2 Technical and operational characteristics of CRSs

A description of the technical and operational characteristics of CRSs can be found in section 7 "High level characteristics and operational and technical requirements" of Report ITU-R M.2330. Additional aspects and technical challenges of CRS technology in IMT networks are described in Report ITU-R M.2242. Cognitive radio systems specific for International Mobile Telecommunications systems.

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[2] Review of the spectrum use of the frequency band 470-960 MHz in Region 1 time for the 2023 World Radiocommunication Conference.

### 4.3 Cognitive capabilities of CRSs

Cognitive capabilities are introduced and described in Report ITU-R M.2225. In particular, the three following capabilities are defined:

a) the capability to obtain the knowledge of its radio operational and geographical environment, its internal state, and the established policies, as well as to monitor usage patterns and users' preferences. This could be accomplished, for instance, by spectrum sensing, using a database, and/or receiving control and management information;

b) the capability to dynamically and autonomously adjust its operational parameters and protocols according to the knowledge in order to achieve predefined objectives, e.g. more efficient utilization of spectrum; and

c) the capability to learn from the results of its actions in order to further improve its performance.

In addition, Report ITU-R M.2330 describes examples of enabling technologies, which are part of the CRS capabilities of obtaining knowledge, decision and adjustment, and learning. Report ITU-R M.2330 further identifies and describes technical features and challenges related to these technologies.

According to Reports ITU-R M.2225 and ITU-R M.2330, "in principle, the introduction and deployment of CRS can take place without the need for any changes to the Radio Regulations. In addition to that, it should be noted that any system of a radiocommunication service that uses CRS technology in a given frequency band will operate in accordance with the provisions of the Radio Regulations governing the use of that band".

As stated in Report ITU-R M.2225, three technical features characterize a CRS node, which are summarized in Table 1.

TABLE 1

**Summary of technical features and capabilities of CRS according to Report ITU-R M.2225**

| Feature | Approach/Method | Description |
|---|---|---|
| 1. Obtaining knowledge | Radio link and network quality assessment | CRS nodes may monitor radio link quality characteristics and network quality parameters, considering the application type. |
| | Listening to a wireless control channel | CRS nodes receive information transmitted (e.g. radio information, operators and technologies available) on a predefined channel. |
| | Spectrum sensing | CRS nodes directly obtain knowledge of the radio environment including unused spectrum. Methods included are matched filtering, energy and cyclostationary detection. |
| | Geo-location | CRS nodes may obtain their location using geo-location techniques. See 5.1. |
| | Database usage | The CRS can access data bases containing information on available frequencies, allowed transmit power levels, operational environment, among others. See 5.1 |
| | Collaboration | CRS nodes may share their obtained knowledge between each other. |

TABLE 1 (*end*)

| Feature | Approach/Method | Description |
|---|---|---|
| 2a. Decision making | Centralized | For coordination of resources between CRS nodes in scenarios where global configuration and optimization are required. The central entity (network resources manager, base station) collects a range of information from CRS and makes a global optimization decision. |
| | Distributed | A CRS may require multiple management entities to make decisions on its reconfiguration (e.g. multiple base stations, mesh topology). |
| 2b. Adjustment of operational parameters/protocols | Software defined radio | A CRS dynamically and autonomously changes their operational parameters and/or protocols by reconfiguration in order to achieve certain predefined objectives. Such parameters may include:<br>– Output power<br>– Operating frequency<br>– Modulation type<br>– Radio access technology<br>– Other parameters/protocols |
| | Multiple hardware modules | |
| 3. Learning | – | Enables performance improvement for the CRS by using stored information of its previous actions and results. |

## 5 General considerations on main network elements facilitating DSA

### 5.1 Geo-location with database access

Geo-location with database access provides information about the temporarily unused/unoccupied spectrum and thus providing protection to incumbent services from harmful interference. In addition to the temporarily unused/unoccupied spectrum information, databases can deliver also the protection requirements related to the use of those spectrum in certain locations such as, for example, the allowed maximum transmit power, exclusion and/or protection zones.

Report ITU-R M.2330 provides different options for implementing the database such as single open database, multiple open databases and proprietary closed databases. In addition to that, challenges of geo-location and database are also depicted in terms of information update, management of the database, security and privacy aspects and interoperability of the database access between various countries (e.g. cross-border coordination).

### 5.2 Spectrum sensing

Spectrum sensing is the capability to detect other signals around a CRS node that can be used to determine temporarily unused/unoccupied spectrum. Spectrum sensing is usable in particular in cases where the level of the detected signal is sufficiently strong, and/or the signal type/form is known beforehand. Report ITU-R M.2330 describes different sensing methods, the performance indicators related to the impact of the different spectrum sensing techniques to other users of the spectrum, the implementation of the sensing methods and, last but not least, the challenges related to spectrum sensing in general.

## 6 Issues and spectrum management challenges related to the use of DSA

This section introduces a number of non-comprehensive issues and challenges related to the use of DSA in temporarily unused/unoccupied spectrum which should be carefully considered when planning to implement such an approach to share spectrum.

### 6.1 General considerations on issues and spectrum management challenges related to the protection of incumbent services.

As for all radio applications, a regulatory framework for DSA-based applications must be defined in accordance with the provisions of the Radio Regulations. Noting that DSA is a spectrum access mechanism to facilitate the shared use of the spectrum, DSA-based application is supposed to operate within the allocated radiocommunication services and therefore the procedures of Article **15** (Interferences) apply.

This would require detailed sharing and compatibility studies to be performed within expert groups of the service to be protected.

Sharing and compatibility studies should consider not only co-channel but also adjacent channel interference. The identification of "temporarily unused/unoccupied spectrum" should only address both cases.

Depending on the nature of the service or the radio application to be protected, compatibility studies will be more or less challenging to be performed. Some examples below reflect some situations where the coexistence scenario may be more difficult to manage and/or may require more attention.

1) Bands allocated to safety of life radiocommunications, radionavigation, aeronautical mobile and aeronautical mobile-satellite services: If dynamic spectrum access devices were to be implemented in the frequency allocations used for safety of life applications, this would pose a major risk to the safe and efficient usage of aviation and maritime services which could not be easily corrected once the devices are in general use.

   The protection of aeronautical services is critical to the safe operation of aircraft. Even minimal levels of interference can put at risk the safety of operational aircraft. Several aeronautical navigations aids only transmit information for reception by passive receivers, the majority of which are based on aircraft and are therefore highly mobile at a range of altitudes and with very large radio line of sight. Additionally, new bi-static radar technology is currently under development (e.g. Recommendation ITU-R M.1638-1), that geographically separate the transmitter and receiver.

2) Bands allocated to Mobile-Satellite and Radiodetermination Satellite Service uplink: MSS transmitting earth stations are mobile by nature therefore the use of a database to locate them seems impractical. Moreover, in bands allocated in the Earth-to-space direction, the permissible interference to ensure the protection of MSS or RDSS links are both the single-entry and aggregate interference produced by all such devices seen by the satellite receiver. Consequently, use of the sensing technology seems to be also impractical.

3) Bands allocated to Mobile-Satellite and Radiodetermination-Satellite Service downlink: The mobile nature of both MSS and RDSS receivers also makes the practical implementation of databases difficult. Sensing is unlikely to be a solution either due to the fact that the transmission that has to be detected comes from the transmitting satellites. The practical difficulties to implement a system able to sense such satellite transmissions should not be underestimated. Moreover, satellite systems cover wide geographic areas, where receivers may or may not be located. Therefore, such a system would lead to a permanent unavailability of any application employing dynamic spectrum access in the satellite downlink bands. An example may better illustrate this phenomenon: radionavigation-satellite systems (RNSS) provide global coverage and if a device

employing dynamic spectrum access would be equipped with a sensor that can appropriately detect RNSS signals, it could only conclude that these signals are indeed able to be received globally. This would therefore not give any indication whether an RNSS receiver is actually close to the device and potentially interfered by its emissions.

4) Bands allocated to the Earth exploration-satellite service (passive) space research service (passive) and radioastronomy service where No. **5.340** of the RR applies: Allowing emissions within a frequency band where No. **5.340** of the RR applies would violate this provision. Moreover, because "all emissions are prohibited" in such bands according to No. **5.340** of the RR, special considerations apply to unwanted emissions from operations in other bands, if they might affect use of the bands subject to No. **5.340** of the RR.

5) Passive service use that cannot be detected by spectrum sensing because no signal characteristic of the use is present: In such cases, only geolocation seems a possible means of preventing unwarranted dynamic access to spectrum. Use of geolocation also must be extended to recognize radio quiet and coordination zones that protect passive service operations on a regional or national level, including in spectrum bands where passive services are not allocated but are locally protected, see Report ITU-R RA.2259.

6) Bands allocated to the Earth exploration-satellite service (EESS) (active): Any sensing of the EESS (active) sensor by systems using the dynamic spectrum access concept may occur too late for the DSA system to cease emissions and avoid interference to the EESS (active) sensor. The use of a database by cognitive radio systems to avoid possible interference with a moving EESS (active) sensor may be challenging.

7) Certain space radiocommunication applications that have time, safety or mission critical links are only detectable by highly sensitive equipment or do not have continuous transmission. For example, spectrum used for communication between space research service (deep space) spacecraft and ultra-sensitive Earth receivers with very large antenna, > 34 metres in diameters, would be undetectable to sensors of a DSA-based application network. Therefore, such spectrum can be mistakenly identified as temporarily unused/unoccupied, but in fact it is utilized for critical mission support and receiving of science data that may be lost if the links were degraded.

For launch and ascent phases of any missions, communication links must be available and uninterrupted during these critical time periods to ensure safety and protection of crew, spacecraft and the mission.

– Sensing strategies.
– Combination with geo-database.
– Spectrum sharing mechanisms among different DSA systems.

Annexes provide information from individual administrations and regions.

8) In the Earth-to-space direction, FSS transmitting earth stations are blanket licensed and ubiquitously deployed in some frequency bands, and hence there is no central database in which the location of these stations is recorded. Therefore, the use of a database to locate these stations is not possible. Moreover, sensing in general will not help a DSA device to determine if it can transmit because, in bands allocated in the Earth-to-space direction, the permissible interference to ensure the protection of FSS links and BSS feeder links from such devices would be specified both as single-entry and aggregate interference. As there would be no way to control the aggregate number of DSA devices seen by the satellite receiver, there would be no way to control the aggregate interference level. Consequently, use of the sensing technology seems to also be impractical in FSS uplink bands (including FSS bands used for BSS feeder uplinks).

9) In the space-to-Earth direction, again the ubiquitous nature of FSS and BSS in some frequency bands precludes the practical implementation of solutions based on databases. Sensing is unlikely to be a solution in general due to the fact that the transmission that has to be detected comes from transmitting satellites and will therefore be very low power. The practical difficulties to implement a system able to sense such satellite transmissions should not be underestimated. In addition, even if realized, such a system would be of practically no use because many satellite systems cover wide geographic areas, where receivers may or may not be located. Therefore, even if a satellite transmission could be detected by a DSA device it would provide no real information as to the possibility of interfering with a satellite receiver.

10) Bands allocated to the broadcasting service: Spectrum sensing of broadcast stations signals may be challenging due to so called hidden node problem and non-continuous operation of some local broadcast stations. The hidden node problem arises because the receiver of the service to be protected is better able to receive the licensed transmissions than a DSAD located in different position or in a low height scenario may be able to (due to their different spatial locations e.g. shielding by buildings). The sensing thresholds taking into account a range of potential DTT receiver configurations appear to be extremely challenging to implement using current technologies. Moreover, in some scenarios, even these low values for the detection threshold do not guarantee a reliable detection of the presence/absence of the broadcasting signals at a distance corresponding to the interference potential of a DSAD. This led to the conclusion that, the sensing technique investigated, if employed by a stand-alone DSAD (autonomous operation), does not seem to be reliable enough to guarantee protection of DTT reception.

The use of a geo-location database to avoid possible interference to DTT receivers appears to be the more reliable option. However, attention still needs to be given to how a geo-location solution would be implemented and the implications to DTT planning. This technique would require a database of DTT service areas that the national administration determines shall be protected for reception at any particular location. This could use be based on the franchised area for commercial broadcasters or the predicted service area in other cases. The determination would have to ensure that extensive deployment of DSADs would not restrict access to DTT services. Moreover, some entity would have to be responsible for setting up and maintaining the geo-location database, which in turn raises questions of:

– how such databases may be operated;

– where may the responsibility be for accuracy of data and verification of input requests; and,

– what arrangements may need to be in place for rectifying and compensating for mistakes?

Such concerns over a traditional database model may be overcome by exploiting block-chain computing technology principles, through which a database could be established and maintained by a number of parties simultaneously, in a reliable and transparent manner. A distributed block-chain based database could provide the basis of mutual trust and successful cooperation between spectrum users, even if their basic interests are in contention with each other.

## 6.2 Issues and spectrum management challenges related to cross-border coordination

Before administrations take a decision on introduction of DSA on their territory cross-border coordination of temporarily unused/unoccupied spectrum should be fulfilled in order to avoid possible harmful interference to the incumbent services of the neighbouring countries.

Recommendation ITU-R SM.1049-1 recommends a method of spectrum management to be used for aiding frequency assignment for terrestrial services in border areas but in case of DSA this method cannot be fully used for number of reasons.

The amount of temporarily unused/unoccupied spectrum is changing at a given location from moment to moment and as a result, administrations will face difficulty to describe frequencies which should be included into Agreements as well as to identify frequencies designated to an individual administration on an exclusive or preferential basis. The issue becomes even more complicated if only sensing CRSs (e.g. systems which are not under control network exploiting of geo-location database to obtain frequency usage requirements) are implemented in coordination zone as administrations will not have information on exact frequencies used by these devices.

At the same time some of the basic principle for cross-border coordination as described in Recommendation ITU-R SM.1049-1 is valid also for DSA – each administration shall have equal right of access to the spectrum. In order to fulfil this principle, as administrations may agree at bilateral or multilateral levels the creation of a coordination zone as well as conditions for the use of spectrum for DSA.

### 6.3 Issues and challenges related to sensing technology to measure spectrum occupancy

An ECC Workshop on "How Measurement of Spectrum Occupancy can help Spectrum Management", held 15 January 2014 in Mainz. The related results are available on the ECC Statement on Spectrum Occupancy Measurement[3]. Here is an extract from the CEPT/ECC statements:

The results of occupancy measurements done with this approach at a limited number of fixed locations could only help to identify possible bands that might be identified for temporarily unused/unoccupied spectrum applications. The decision whether a particular frequency can be used at a certain location, e.g. as part of dynamic spectrum access or in relation to geo-location databases, cannot be drawn from these measurement results.

PMSE, SRD and RFID equipment as well as satellite applications illustrate why single low-cost sensors are not sufficient to show the reality in a frequency range from 30 MHz to 6 000 MHz. To give a detailed inventory of the spectrum usage in a big city, a vast amount of fixed receiving stations or other methods such as mobile data collection would be necessary.

### 6.4 Issues and frequency spectrum challenges related to the implementation of a DSA-based application

**Spectrum resource issues**

The use of dynamic spectrum access (DSA) in a given frequency band allocated to more than one service on the primary or secondary basis should not impede the future development of other services in those bands. Spectrum availability and flexibility regarding improvement of spectrum conditions in which primary services operate should not be impacted by DSA-based application. Overall, this implies that practical implementation and authorisation can be responsive to the evolution of national policies in terms of primary users' spectrum allocation. Risks, particularly for industry stakeholders, associated with uncertainties on the availability of spectrum, whether locally or as a consequence of change in primary users' spectrum allocation should also be addressed.

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3 https://cept.org/ecc/groups/ecc/client/introduction/ecc-statement-on-spectrum-occupancy-workshop.

**National Regulatory Authority (NRA) responsibilities and database complexity**

Administrations should keep control through database management by decision both 1) in effective implementation of a national regulatory framework allowing DSA based application subject to market demand and proper impact assessment on costs and benefits, and 2) on the effective frequency band where device operated under DSA-based application may operate.

Database assisted operation is a new approach to manage spectrum and as a result there is no experience or a clearly defined framework for regulating databases. When considering how to put this in place, an NRA is likely to consider the following questions:

– How to ensure that only databases approved by an NRA provide service to devices?

– What is the legal instrument that enables device operation?

– What are the obligations of a Database provider?

Decision and choices about mitigation of interference between different DSA-based applications would depend on the assessment of the risk made by an NRA. For instance, when the density of use is very low, the best solution may be to do nothing as the likelihood of interference will be low. The choice of the most adequate solution is not straightforward and there is a risk of making the wrong regulatory choices, in the absence of a clear understanding of what the interference scenario might look like.

An NRA has to engage in a number of tasks related to the management of the database:

– Collect and process incumbent data;

– Calculate spectrum availability;

– Select, approve and regulate databases – or alternatively run a database.

Following the various exchanges of information in relation with database management, an NRA and incumbents will face costs from collecting, aggregating and updating data on available spectrum for use by DSA-based applications. An NRA will also incur costs in establishing and updating the algorithm and monitoring the accuracy of the third party database/s used. Although making spectrum available to such application should not significantly increase the risk of interference to the licence holder if the coexistence framework is done correctly, there may nevertheless be an increase in the enforcement costs to an NRA for detecting and resolving interference. Finally, the database provider/s will also incur costs in setting up their systems and responding to DSA-based application requests.

However, those costs can be greatly reduced if the NRA has enough information and control over the primary and secondary service frequency licences. For instance, radio services, such as broadcasting and fixed, usually require providing the NRA with relevant technical characteristics before obtaining a frequency use licence. That information is enough for obtaining the available spectrum to be used by DSA-based applications. Furthermore, the detection and resolution of interference caused by DSA-based applications can be assisted by geolocation databases with the ability to order the cessation of transmission of the suspected interferers.

Finally, administrations should take due account of the challenges associated with conformity assessment and enforcement for a database system that would provide the basis for authorizing low-cost DSA-based devices potentially deployed in very high numbers.

**Issues related to the prediction tool which assists the database to grant spectrum resources**

The calculation engine translates the information on incumbent services and the technical characteristics and location of the device of the DSA-based application, onto a list of allowed frequencies and associated transmission powers for devices. It should be noted that, depending on national frequency management organisation, the regulator itself may carry some of the translation processes by providing a dataset of results to the databases – in the form of powers and channels, available for devices of the DSA-based application usage at all points on the grid covering the country. The co-existence framework for calculating the number of devices that the DSA-based application powers, based on pre-agreed interference limits can indeed require a significant number of complex calculations, often using data which is sensitive to the incumbent service.

As a critical requirement, an NRA will want to be sure that a database performs the calculation process correctly as errors could lead to interference to incumbents.

Furthermore, an NRA should carefully choose a radio propagation model to be implemented in the database calculation engine. In this regard, an NRA should consider the trade-off between the calculation speed and the accuracy of the DSA transmitter interference contour prediction. Also, if accurate cartographic data is available, deterministic propagation models should be preferred over statistical ones, given that statistical models usually underestimate or overestimate coverage and interference contours can function in rough terrain scenarios, affecting the DSA-base application spectrum availability and/or the interference protection to the incumbent services.

**Consistency of the overall architecture of the DSA system**

The interactions between radiocommunication systems and database(s) need to be clearly articulated and dependencies between network sensitivity and database(s) fully explained, including a plan for when communication and/or sensitivity failure occurs between the, devices which operate under a DSA-based application and database(s) as well as self-diagnostics to access proper functions.

An NRA should check if the entire system is consistent and does not leave any opportunity to deviate from the national spectrum regulation in place (e.g. no possibility to modify the power of equipment by manual operation, which guarantees that a device DSA-based operation may only transmit in the territory of a country if it has successfully discovered a geo-location database approved by an NRA.

Also, the NRA should avoid DSA regulatory frameworks in which technical characteristics of the DSA transmitters are provided by a human user instead of being automatically acquired by the DSA devices. For instance, if the location coordinates of a DSA transmitter are allowed to be manually inputted by a human user instead of being automatically acquired, unintentional typographic errors can lead the geolocation database to provide channels that are not available in the real DSA transmitter location, causing interference to incumbent users. Also, a user can intentionally input different coordinates to obtain better spectrum availability for a given DSA device, which is difficult to distinguish from an unintentional error. This situation can not only happen with the geographic coordinates but with other technical parameters.

In this regard, the NRA should identify and account for the DSA-based device technical characteristics that are required to be known and cannot be obtained accurately through automatic means. For example, if the antenna height above terrain level, which is important to be known for the available spectrum calculation, is not accurately obtained through GPS systems; in this case, the NRA might use the maximum allowed antenna height (established in the regulation) for the available spectrum calculation.

**Interference avoidance challenges**

Use of mixed models some systems operating with some operational parameters (defined power, identified mitigation techniques to ensure intra-coexistence, etc.) and/or to be defined geolocation database, while others utilize lower power and/or antenna/e.i.r.p. elevation angle mask needs to be studied to determine if such mixed use can be allowed without harmful interference into incumbent services.

Rules defining spectrum availability and associated transmission powers are set by an NRA and are implemented in database(s).

Furthermore, the NRA should be aware that interference caused by DSA-based applications occurs not only in co-channel and first adjacent channels, but also in higher adjacent channels. Also, it is important to note that the physical layer of some DSA-based applications is not currently standardized, therefore transmitters made by different manufacturers affect incumbent services differently. Because of this, the NRA should measure the interference potential of DSA-based applications (in the form of protection ratios, for instance) to quantify the available spectrum for those applications as well as to establish the respective regulatory framework.

**Geolocation issues**

What methods (e.g. Global Positioning Satellite (GPS) system, IP address to location service and self-positioning system) are the most appropriate to ensure precise location of each device in particular in an indoor environment? How does the location update?

The use of any GPS receiver requires a clear reception of the GPS signal; therefore, the obvious difficulty exists for any indoor location application, as a good GPS signal is necessary for an accurate location. However, a GPS receiver cannot work when it is located indoors.

In addition, some administrations may have regulatory provisions in place that could prevent the disclosure of the exact location of any equipment.

**Questions to be addressed in database and system operation**

How often do the terminals scan the database? It is not possible for all terminals to be listening at the same time. Thus, it is impossible for the equipment to cease all transmission on the channel at once. Does the scanning time provide enough time for all terminals to cease operation and not cause interference to incumbent services?

In addition, taking into account that a number of user terminals are battery dependent, a frequent scan of the database has an impact on power consumption. It is essential to assess to what extent this operation degrades the battery autonomy of the terminal (this can be a source of encouragement for certain users to tamper with the device).

**Sensing capabilities**

It appears relevant to ensure that the sensing technique which is used can perform the requirements which are defined to protect the incumbent service. Otherwise, the impact of the implementation of these requirements on the systems should also be assessed.

The choice of the sensing technology is essential for a good operation of the mechanism. Which sensing technology is the most appropriate for which purpose?

| Narrowband sensing technology [1],[2] | Advantages | Disadvantages |
|---|---|---|
| Energy detection | – Non-coherent detection method which does not require prior information<br>– Low computational cost | – Poor performance under low SNR<br>– Cannot differentiate users |
| Waveform based detection | – Shorter measurement time<br>– High reliability | – Requires prior information |
| Cyclostationary feature | – Valid in low SNR region<br>– Robust against interference | – Requires partial prior information<br>– High computational cost |

| **Narrowband sensing technology [1],[2]** | **Advantages** | **Disadvantages** |
|---|---|---|
| Matching filtering | – Optimal performance by maximizing SNR<br>– Low computational cost | – Requires prior information of the primary user<br>– Increase of implementation complexity |

| **Wideband sensing technology [2]** | | **Advantages** | **Disadvantages** |
|---|---|---|---|
| Nyquist wideband sensing | Standard ADC | – Simple structure | – High sampling rate<br>– High computational cost |
| | Filter bank sampling | – Low sampling rate<br>– High dynamic range | – High implementation complexity |
| Sub-Nyquist wideband sensing | Compressive sensing | – Low sampling rate<br>– Low signal acquisition cost | – Sensitive to model mismatch |
| | Multichannel sub-Nyquist sampling | – Low sampling rate<br>– Robust to model mismatch | – Requires multiple sampling channels |

Note – All Annexes to this Report are for information only.

# Annex 1

## Model of a cognitive system based on geolocation database

### General provisions

A geolocation database is the element of the automated system of radio spectrum management for communication networks using the principle of cognitive radio. Geolocation database communicates directly with the Master Devices of cognitive radio networks. The database allocates frequency channels, controls transmission parameters of cognitive devices and ensures electromagnetic compatibility between cognitive radio and other radio electronic devices operating in overlapping or adjacent bands.

Geolocation database shall have information about locations and operating parameters of all radio electronic devices within the frequency band under consideration, or about any special limiting masks used in the case when it is difficult to determine locations or technical parameters of the protected radio electronic devices.

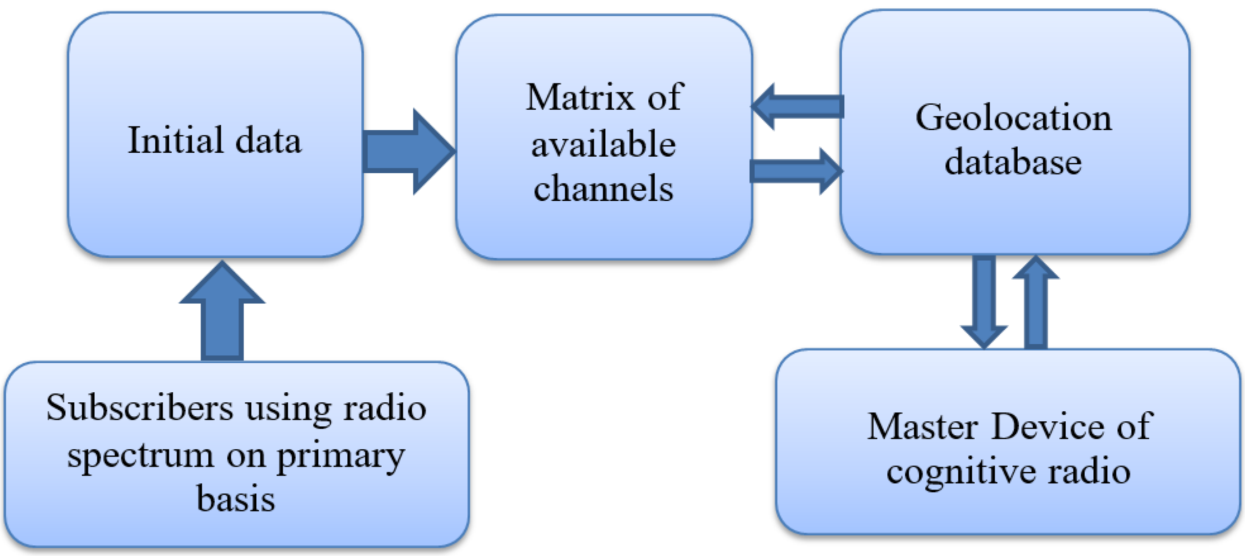
The functioning of geolocation database could be based on the matrix containing information about the availability of some frequency channels at each point of a given area for a given frequency band, indicating maximum permissible technical parameters.

### Generation of the matrix of available channels

The matrix of available channels is generated using information from the database of regulatory body that contains information about all radio electronic devices with valid authorizations, and their specifications to the extent sufficient to calculate electromagnetic compatibility.

Generation of the matrix may be carried out by a separate server located remotely from geolocation database. In this case, the operator of the geolocation database will have a matrix of available frequency channels but will not have information on specific radio electronic devices and technical parameters which were used for the matrix generation.

**Principle of the cognitive system using geolocation database**



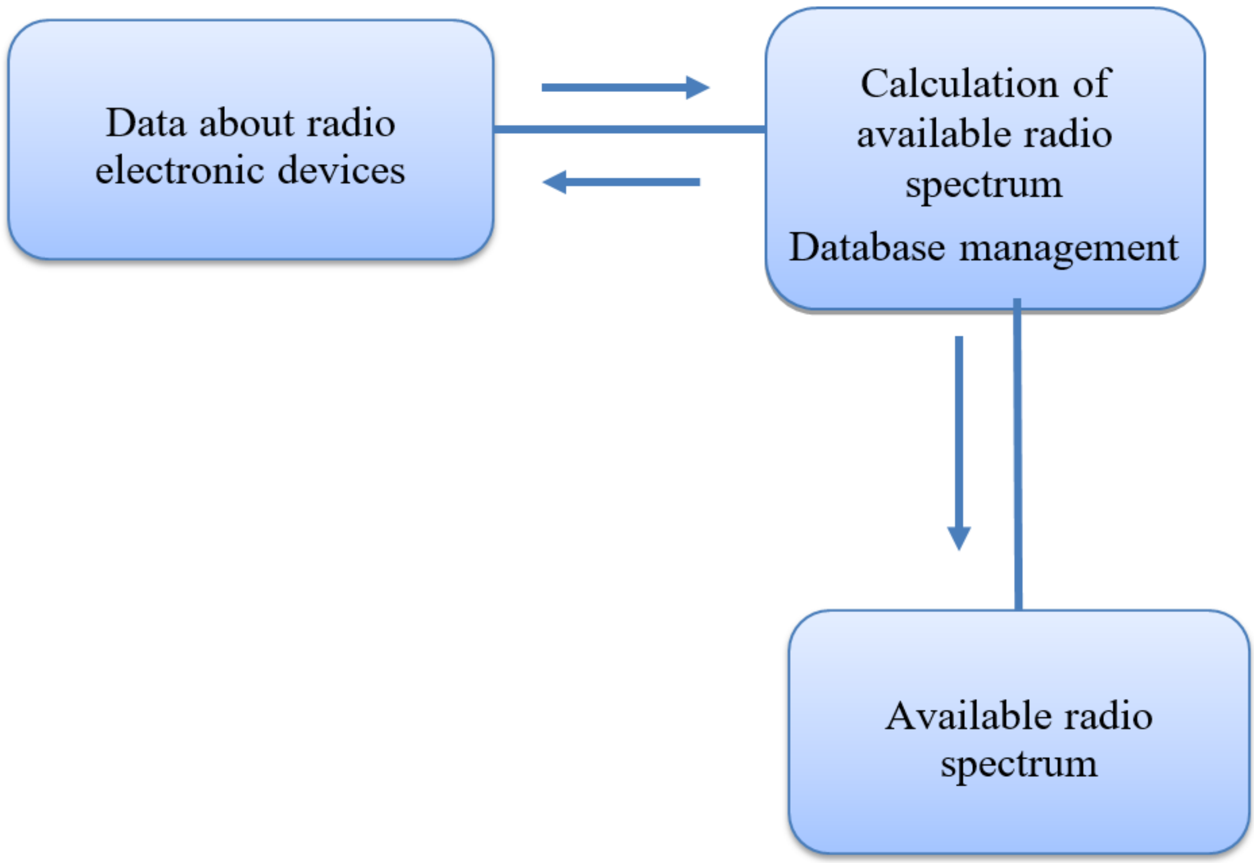
Coverage area of geolocation database can be divided into small portions of predetermined size, i.e. "pixels". Each "pixel" contains information about the protected channels. On this basis, a set of available channels can be determined using e.r.p. level and other parameters necessary for operation of cognitive devices. The number of available channels in each "pixel" may be determined by superimposing the spectrum occupancy information received from various services, so there is no need to store information about various protected radio devices. It is enough to know only the number of channels per pixel, which are free for cognitive devices.

A size of a "pixel" depends on the decisions taken at the planning phase when filling the geolocation database, but a size of the order of 200 m × 200 m assumed appropriate in most cases. This size of "pixel" is the best, since larger size can lead to inefficient use of geolocation database, i.e. to a reduced available spectrum, and smaller size will lead to a large volume of calculations and large amount of data to be send to a device. So, the problem reduces to considering constraints on the set of "pixels", in order to identify the channels and power levels available for cognitive devices.

Having received information about operating radio electronic devices, a number of available channels are calculated for each "pixel" in advance, resulting in a matrix of available channels. Thus, real-time calculations are significantly reduced.

After a certain period of time (set by the regulator body) the number of available channels in each "pixel" should be re-calculated, and a new matrix of available channels re-filled. The matrix of available channels is stored in the geolocation database.

**Calculation of available radio spectrum**




The calculations may use different propagation models (e.g. Recommendation ITU-R P.1546, Free Space, Hata, etc.). Having calculated the power in a given "pixel", available channels are calculated taking into account specified thresholds. If the calculated power is lower than the threshold, then this channel is considered to be free; if the power value is above the threshold, then the channel is considered to be busy.

**Initial data**

The following data should be used as the initial data for the calculation of the matrix of available channels:

a) Data about radio electronic devices operating under licences:
- identification number (ID) of radio station or device
- type of transmitter
- location (geographic coordinates)
- existing channels (channels are filed which operated by primary users)
- transmit power or e.r.p. of licenced device (this information is needed to calculate the allowable power level for secondary devices)
- height of transmitting antenna (for calculation of the propagation loss)
- radiation pattern of transmitting antenna
- regulations for protection of existing devices, territory, etc.

b) Data about other radio electronic devices such as wireless microphones (such devices shall be registered in order to ensure proper functioning of the whole cognitive radio system):
- type of device (wireless microphones, cameras or other type of secondary devices)
- identification number of a device
- device location
- channels used
- transmit power.

c) Data about cognitive devices and devices operating on a secondary basis:
- device type (fixed or portable / mobile cognitive device)
- device ID
- production serial number
- device location
- used channels (channels that are currently in use by cognitive devices).

d) Regulatory information:
- regulator ID
- used propagation models and algorithms of the system operation
- power thresholds corresponding to a free channel
- restrictions under which the operation of cognitive devices should be deactivated.

**Data about the available radio spectrum**

After available channels for all "pixels" are calculated, the matrix of available channels stored in the geolocation database. When a user wishes to know about the available spectrum, operator of the geolocation database, having direct access to this data, provides a list of available channels without any calculations in real time taking into account user's location. This list will contain the following information:

– identifier of the "pixel" or its geographic coordinates;

– numbers of available channels (available for a certain "pixel");

– allowable technical characteristics of cognitive devices, such as the maximum allowable radiation power and valid time for the information provided.

When a given frequency band is shared between radio services, matrices of available channels are calculated for each radio service, and then summed up.

Geolocation database should provide the choice of frequency bands and specifications for cognitive radio systems so as to ensure both the possibility of their operation and operation of other radio electronic devices without interference. The other radio electronic devices (being primary spectrum users) have a priority in the use of radio channels over cognitive radio systems.

Before the time the cognitive radio device will be able to transmit, it should contact the geolocation database and exchange service information to receive a list of available channels – frequency bands that can be used by the cognitive device without interference to primary users.

Cognitive devices shall communicate with the database to adjust their characteristics such as the operating frequency band which depends on the current time and location, as well as the transmitter parameters.

# Annex 2

# Sensing technologies

## 1 Types of sensing technologies

Spectrum sensing technologies can be classified into narrowband and wideband spectrum sensing technologies. Narrowband spectrum sensing technologies focus on exploiting spectral opportunities over narrow frequency range which is sufficiently narrow such that the channel frequency response can be considered flat. Wideband spectrum sensing aims to find more spectral opportunities over a wide frequency range and achieve higher opportunistic aggregate throughput.

Table A2-1 categorizes the advantages and disadvantages of the traditional narrowband spectrum sensing technologies.

TABLE A2-1

| Narrowband sensing technology [1],[2] | Advantages | Disadvantages |
|---|---|---|
| Energy detection | – Non-coherent detection method which does not require prior information<br>– Low computational cost | – Poor performance under low SNR<br>– Cannot differentiate users |
| Waveform based detection | – Shorter measurement time<br>– High reliability | – Requires prior information |
| Cyclostationary feature | – Valid in low SNR region<br>– Robust against interference | – Requires partial prior information<br>– High computational cost |
| Matching filtering | – Optimal performance by maximizing SNR<br>– Low computational cost | – Requires prior information of the primary user<br>– Increase of implementation complexity |

Wideband spectrum sensing can be broadly categorized into two types: Nyquist wideband sensing and sub-Nyquist wideband sensing. The former type processes digital signals at the rate of equal or higher than the Nyquist rate, whereas the latter type processes digital signals at the rate of lower than the Nyquist rate.

Table A2-2 lists the advantages and disadvantages of the existing wideband spectrum sensing technologies.

TABLE A2-2

| Wideband sensing technology[2] | | Advantages | Disadvantages |
|---|---|---|---|
| Nyquist wideband sensing | Standard ADC | – Simple structure | – High sampling rate<br>– High computational cost |
| | Filter bank sampling | – Low sampling rate<br>– High dynamic range | – High implementation complexity |
| Sub-Nyquist wideband sensing | Compressive sensing | – Low sampling rate<br>– Low signal acquisition cost | – Sensitive to model mismatch |
| | Multichannel sub-Nyquist sampling | – Low sampling rate<br>– Robust to model mismatch | – Requires multiple sampling channels |

## 2 Sensing technology using dynamic frequency selection

Dynamic frequency selection (DFS) is one of the mitigation techniques for sharing spectrum. A wireless access system (WAS) shall use DFS function to provide adequate protection to radars in the 5 GHz band.

List of relevant Recommendations and Reports relating to DFS in WAS are listed below:

– Recommendation ITU-R M.1652-1 – Dynamic frequency selection in wireless systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band

– Recommendation ITU-R M.1461-2 – Procedures for determining the potential interference between radars operating the radiodetermination service and systems in other services

– Recommendation ITU-R M.1638-1 – Characteristics of and protection criteria for sharing studies for radiolocation (except ground based meteorological radars) aeronautical radionavigation radars operating in the frequency bands between 5 250 and 5 850 MHz
– Report ITU-R M.2034 – Impact of radio detection requirements of dynamic frequency selection on 5 GHz wireless access system receivers

DFS is achieved by detecting interference from radar system and avoiding co-channel operation. Radar detection is required when operating channels whose bandwidth falls partly or completely within the frequency range 5 250 MHz to 5 350 MHz or 5 470 MHz to 5 725 MHz. This requirement applies to all type of WAS devices regardless of the type of the communication between these devices.

Table A2-3 specifies the detection, operational and response requirements of DFS.

TABLE A2-3

| Parameter | Value |
|---|---|
| DFS detection threshold | –62 dBm for devices with a maximum e.i.r.p. of < 200 mW and<br>–64 dBm for devices with a maximum e.i.r.p. of 200 mW to 1 W averaged over 1 μs |
| Channel availability check time | 60 s |
| Non-occupancy period | 30 min |
| Channel move time | ≤ 10 s |

# Annex 3

## Characteristics and/or protection criteria for radiocommunication services for which the allocated bands may be used by CRSs

List of relevant Recommendations and Reports relating to characteristics and/or protection criteria for different radiocommunication services is provided below for illustration.

### 1 Land mobile and fixed services

– Recommendation ITU-R M.478-5 – Technical characteristics of equipment and principles governing the allocation of frequency channels between 25 and 3 000 MHz for the FM land mobile service
– Recommendation ITU-R M.1184-3 – Technical characteristics of mobile satellite systems in the frequency bands below 3 GHz for use in developing criteria for sharing between the mobile-satellite service and other services

(NOTE – Contains the technical characteristics of systems operating in the land mobile-satellite service.)

– Recommendation ITU-R F.1402 – Frequency sharing criteria between a land mobile wireless access system and a fixed wireless access system using the same equipment type as the mobile wireless access system

– Recommendation ITU-R M.1450-5 – Characteristics of broadband radio local area networks
– Recommendation ITU-R M.1453-2 – Intelligent transport systems – Dedicated short range communications at 5.8 GHz
– Recommendation ITU-R M.1767 – Protection of land mobile systems from terrestrial digital video and audio broadcasting systems in the VHF and UHF shared bands allocated on a primary basis
– Recommendation ITU-R M.1739 – Protection criteria for wireless access systems, including radio local area networks, operating in the mobile service in accordance with Resolution **229 (WRC-03)** in the bands 5 150-5 250 MHz, 5 250-5 350 MHz and 5 470-5 725 MHz
– Recommendation ITU-R M.1808-1 – Technical and operational characteristics of conventional and trunked land mobile systems operating in the mobile service allocations below 869 MHz to be used in sharing studies in bands below 960 MHz (NOTE – Section 2.1 of Annex 1 contains the protection criteria for the mobile service to be used in the sharing studies "that an interference-to-noise ratio of I/N = −6 dB be used to determine the interference impact for land mobile systems, and that for applications with greater protection requirements, such as public protection and disaster relief (PPDR), an I/N of −10 dB may be used".)
– Recommendation ITU-R M.1823 – Technical and operational characteristics of digital cellular land mobile systems for use in sharing studies
– Recommendation ITU-R M.1824-1 – System characteristics of television outside broadcast, electronic news gathering and electronic field production in the mobile service for use in sharing studies
– Report ITU-R F.2086-1 – Technical and operational characteristics and applications of broadband wireless access in the fixed service
– Report ITU-R M.2116-2 – Characteristics of broadband wireless access systems operating in the land mobile service for use in sharing studies
– Report ITU-R M.2228-1 – Advanced intelligent transport systems (ITS) radiocommunications
– Report ITU-R M.2242 – Cognitive radio systems specific for International Mobile Telecommunications systems

## 2 Mobile-satellite and radiodetermination-satellite services (MSS and RDSS)

– Recommendation ITU-R M.1039-3 – Co-frequency sharing between stations in the mobile service below 1 GHz and mobile earth stations of non-geostationary mobile-satellite systems (Earth-space) using frequency division multiple access (FDMA)
– Recommendation ITU-R M.1184-3 – Technical characteristics of mobile satellite systems in the frequency bands below 3 GHz for use in developing criteria for sharing between the mobile-satellite service and other services
– Recommendation ITU-R M.1318-1 – Evaluation model for continuous interference from radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz and 5 010-5 030 MHz bands
– Recommendation ITU-R M.1787-3 – Description of systems and networks in the radionavigation-satellite service (space-to-Earth and space-to-space) and technical

characteristics of transmitting space stations operating in the bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz

– Recommendation ITU-R M.1901-2 – Guidance on ITU-R Recommendations related to systems and networks in the radionavigation-satellite service operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz, 5 000-5 010 MHz and 5 010-5 030 MHz

– Recommendation ITU-R M.1902-1 – Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 215-1 300 MHz

– Recommendation ITU-R M.1903-1 – Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) and receivers in the aeronautical radionavigation service operating in the band 1 559-1 610 MHz

– Recommendation ITU-R M.1904-1 – Characteristics, performance requirements and protection criteria for receiving stations of the radionavigation-satellite service (space to-space) operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz

– Recommendation ITU-R M.1905-1 – Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 164-1 215 MHz

– Recommendation ITU-R M.1906-1 – Characteristics and protection criteria of receiving space stations and characteristics of transmitting earth stations in the radionavigation satellite service (Earth-to-space) operating in the band 5 000-5 010 MHz

– Recommendation ITU-R M.2030 – Evaluation method for pulsed interference from relevant radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz frequency bands

– Recommendation ITU-R M.2031-1 – Characteristics and protection criteria of receiving earth stations and characteristics of transmitting space stations of the radionavigation-satellite service (space-to-Earth) operating in the band 5 010-5 030 MHz

Recommendation ITU-R M.1091 – Reference off-axis radiation patterns for mobile earth station antennas operating in the land mobile-satellite service in the frequency range 1 to 3 GHz

– Recommendation ITU-R M.1229 – Performance objectives for the digital aeronautical mobile-satellite service (AMSS) channels operating in the bands 1 525 to 1 559 MHz and 1 626.5 to 1 660.5 MHz not forming part of the ISDN

– Recommendation ITU-R S.1427-1 – Methodology and criterion to assess interference from terrestrial wireless access system/radio local area network transmitters to non-geostationary-satellite orbit mobile-satellite service feeder links in the band 5 150-5 250 MHz

– Recommendation ITU-R M.1454 – e.i.r.p. density limit and operational restrictions for RLANS or other wireless access transmitters in order to ensure the protection of feeder links of non-geostationary systems in the mobile-satellite service in the frequency band 5 150-5 250 MHz

– Recommendation ITU-R M.1475 – Methodology for derivation of performance objectives of non-geostationary mobile-satellite service systems operating in the 1-3 GHz band not using satellite diversity

– Recommendation ITU-R M.1799 – Sharing between the mobile service and the mobile-satellite service in the band 1 668.4-1 675 MHz
– Recommendation ITU-R M.2046 – Characteristics and protection criteria for non-geostationary mobile-satellite service systems operating in the band 399.9-400.05 MHz

## 3 Other services

Recommendation ITU-R F.758 provides the protection criteria and other characteristics for FWS in various bands.

**Aeronautical mobile (route) service**

– Recommendation ITU-R M.1827-1* – Guideline on technical and operational requirements for stations of the aeronautical mobile (R) service limited to surface application at airports in the frequency band 5 091-5 150 MHz
– Report ITU-R M.2121 – Guidelines for AM(R)S sharing studies in the 960-1 164 MHz band
– Report ITU-R M.2205 – Results of studies of the AM(R)S allocation in the band 960-1 164 MHz and of the AMS(R)S allocation in the band 5 030-5 091 MHz to support control and non-payload communications links for unmanned aircraft systems
– Report ITU-R M.2235 – Aeronautical mobile (route) service sharing studies in the frequency band 960-1 164 MHz
– Report ITU-R M.2171 – Characteristics of unmanned aircraft systems and spectrum requirements to support their safe operation in non-segregated airspace
– Report ITU-R M.2237 – Compatibility study to support the line-of-sight control and non-payload communications link(s) for unmanned aircraft systems proposed in the frequency band 5 030-5 091 MHz
– Report ITU-R M.2238 – Compatibility study to support line of sight control and non-payload communications links for unmanned aircraft systems proposed in the frequency band 5 091-5 150 MHz

**Aeronautical mobile**

– Recommendation ITU-R M.1459 – Protection criteria for telemetry systems in the aeronautical mobile service and mitigation techniques to facilitate sharing with geostationary broadcasting-satellite and mobile-satellite services in the frequency bands 1 452-1 525 MHz and 2 310-2 360 MHz
– Recommendation ITU-R M.1828 – Technical and operational requirements for aircraft stations of aeronautical mobile service limited to transmissions of telemetry for flight testing in the bands around 5 GHz
– Recommendation ITU-R M.2089 – Technical characteristics and protection criteria for aeronautical mobile service systems in the frequency range 14.5-15.35 GHz
– Recommendation ITU-R M.2114* – Technical characteristics and protection criteria for aeronautical mobile service systems in the frequency bands 22.5-23.6 and 25.25-27.5 GHz
– Report ITU-R M.2118 – Compatibility between proposed systems in the aeronautical mobile service and the existing fixed-satellite service in the 5 091-5 250 MHz band
– Report ITU-R M.2119 – Sharing between aeronautical mobile telemetry systems for flight testing and other systems operating in the 4 400-4 940 and 5 925-6 700 MHz bands
– Report ITU-R M.2221 – Feasibility of MSS operations in certain frequency bands

**Radionavigation Service**

– Recommendation ITU-R M.1461-2* – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services

– Recommendation ITU-R M.1796-2 – Characteristics of and protection criteria for terrestrial radars operating in the radiodetermination service in the frequency band 8 500-10 680 MHz

– Recommendation ITU-R M.1851-1 – Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses

**Aeronautical Radionavigation Service**

– Recommendation ITU-R M.1461-2* – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services

– Recommendation ITU-R M.1464-2* – Characteristics of radiolocation radars, and characteristics and protection criteria for sharing studies for aeronautical radionavigation and meteorological radars in the radiodetermination service operating in the frequency band 2 700-2 900 MHz

– Recommendation ITU-R M.1584 – Method for determining coordination distances, in the 5 GHz band, between the international standard microwave landing system stations operating in the aeronautical radionavigation service and stations of the radionavigation-satellite service (Earth-to-space)

– Recommendation ITU-R M.1638-1* – Characteristics of and protection criteria for sharing studies for radiolocation (except ground based meteorological radars) aeronautical radionavigation radars operating in the frequency bands between 5 250 and 5 850 MHz

– Recommendation ITU-R M.1639-1 – Protection criterion for the aeronautical radionavigation service with respect to aggregate emissions from space stations in the radionavigation-satellite service in the band 1 164-1 215 MHz

– Recommendation ITU-R M.1642-2 – Methodology for assessing the maximum aggregate equivalent power flux-density at an aeronautical radionavigation service station from all radionavigation-satellite service systems operating in the 1 164-1 215 MHz band

– Recommendation ITU-R M.1830 – Technical characteristics and protection criteria of aeronautical radionavigation service systems in the 645-862 MHz frequency band

– Recommendation ITU-R M.2007 – Characteristics of and protection criteria for radars operating in the aeronautical radionavigation service in the frequency band 5 150-5 250 MHz

– Recommendation ITU-R M.2008-1 – Characteristics and protection criteria for radars operating in the aeronautical radionavigation service in the frequency band 13.25-13.40 GHz

– Recommendation ITU-R M.2013 – Technical characteristics of, and protection criteria for non-ICAO aeronautical radionavigation systems, operating around 1 GHz

– Report ITU-R M.2112 – Compatibility/sharing of airport surveillance radars and meteorological radar with IMT systems within the 2 700-2 900 MHz band

– Recommendation ITU-R M.1851-1 – Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses

– Recommendation ITU-R M.2059 – Operational and technical characteristics and protection criteria of radio altimeters utilizing the band 4 200-4 400 MHz

**Maritime Radionavigation Service**

– Recommendation ITU-R M.824-4 – Technical parameters of radar beacons
– Recommendation ITU-R M.1176-1 – Technical parameters of radar target enhancers
– Recommendation ITU-R M.629-1 – Use of the radionavigation service of the frequency bands 2 900-3 100 MHz, 5 470-5 650 MHz, 9 200-9 300 MHz, 9 300-9 500 MHz and 9 500-9 800 MHz
– Recommendation ITU-R M.1461-2* – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services
– Recommendation ITU-R M.1851-1 – Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses
– Report ITU-R M.2050 – Test results illustrating the susceptibility of maritime radionavigation radars to emissions from digital communication and pulsed systems in the bands 2 900-3 100 MHz and 9 200-9 500 MHz
– Recommendation ITU-R M.1372-1 – Efficient use of the radio spectrum by radar stations in the radiodetermination service
– Report ITU-R M.2032 – Tests illustrating the compatibility between maritime radionavigation radars and emissions from radiolocation radars in the band 2 900-3 100 MHz
– Recommendation ITU-R M.2058 – Characteristics of a digital system, named navigational data for broadcasting maritime safety and security related information from shore-to-ship in the maritime HF frequency band

**Radionavigation Service**

– Recommendation ITU-R M.1227-2 – Technical and operational characteristics of wind profiler radars in bands in the vicinity of 1 000 MHz
– Recommendation ITU-R M.1460-2* – Technical and operational characteristics and protection criteria of radiodetermination radars in the frequency band 2 900-3 100 MHz
– Recommendation ITU-R M.1461-2* – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services
– Recommendation ITU-R M.1462-2 – Characteristics of and protection criteria for radars operating in the radiolocation service in the frequency range 420-450 MHz
– Recommendation ITU-R M.1463-3 – Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz
– Recommendation ITU-R M.1465-3* – Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 3 100-3 700 MHz
– Recommendation ITU-R M.1638-1* – Characteristics of and protection criteria for sharing studies for radiolocation (except ground based meteorological radars) and aeronautical radionavigation radars operating in the frequency bands between 5 250 and 5 850 MHz
– Recommendation ITU-R M.1849-2* – Technical and operational aspects of ground-based meteorological radars
– Recommendation ITU-R M.1851-1 – Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses
– Report ITU-R M.2013 – Wind profiler radars

– Report ITU-R M.2112 – Compatibility/sharing of airport surveillance radars and meteorological radar with IMT systems within the 2 700-2 900 MHz band
– Report ITU-R M.2136 – Theoretical analysis and testing results pertaining to the determination of relevant interference protection criteria of ground-based meteorological radars
– Recommendation ITU-R M.1372-1 – Efficient use of the radio spectrum by radar stations in the radiodetermination service
– Recommendation ITU-R M.1464-2* – Characteristics of radiolocation radars, and characteristics and protection criteria for sharing studies for aeronautical radionavigation and meteorological radars in the radiodetermination service operating in the frequency band 2 700-2 900 MHz
– Report ITU-R M.2032 – Tests illustrating the compatibility between maritime radionavigation radars and emissions from radiolocation radars in the band 2 900-3 100 MHz

**FSS and BSS**

– Recommendation ITU-R S.465-6 – Reference radiation pattern of earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz
– Recommendation ITU-R S.466-6 – Maximum permissible level of interference in a telephone channel of a geostationary-satellite network in the fixed-satellite service employing frequency modulation with frequency-division multiplex, caused by other networks of this service
– Recommendation ITU-R S.483-3 – Maximum permissible level of interference in a television channel of a geostationary-satellite network in the fixed-satellite service employing frequency modulation, caused by other networks of this service
– Recommendation ITU-R S.523-4 – Maximum permissible levels of interference in a geostationary-satellite network in the fixed-satellite service using 8-bit PCM encoded telephony, caused by other networks of this service
– Recommendation ITU-R S.524-9 – Maximum permissible levels of off-axis e.i.r.p. density from earth stations in geostationary-satellite orbit networks operating in the fixed-satellite service transmitting in the 6 GHz, 13 GHz, 14 GHz and 30 GHz frequency bands
– Recommendation ITU-R S.728-1 – Maximum permissible level of off-axis e.i.r.p. density from very small aperture terminals (VSATs)
– Recommendation ITU-R S.735-1 – Maximum permissible levels of interference in a geostationary-satellite network for an HRDP when forming part of the ISDN in the fixed-satellite service caused by other networks of this service below 15 GHz
– Recommendation ITU-R S.1323-2 – Maximum permissible levels of interference in a satellite network (GSO/FSS; non-GSO/FSS; non-GSO/MSS feeder links) in the fixed-satellite service caused by other co-directional FSS networks below 30 GHz
– Recommendation ITU-R S.1426 – Aggregate power flux-density limits, at the FSS satellite orbit for radio local area network (RLAN) transmitters operating in the 5 150-5 250 MHz band sharing frequencies with the FSS (RR No. S**5.447A**)
– Recommendation ITU-R S.1427-1 – Methodology and criterion to assess interference from terrestrial wireless access system/radio local area network transmitters to non-geostationary-satellite orbit mobile-satellite service feeder links in the band 5 150-5 250 MHz

– Recommendation ITU-R S.1432-1 – Apportionment of the allowable error performance degradations to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz
– Recommendation ITU-R S.1528 – Satellite antenna radiation patterns for non-geostationary orbit satellite antennas operating in the fixed-satellite service below 30 GHz
– Recommendation ITU-R S.1587-3 – Technical characteristics of earth stations on board vessels communicating with FSS satellites in the frequency bands 5 925-6 425 MHz and 14-14.5 GHz which are allocated to the fixed-satellite service
– Recommendation ITU-R S.1711-1 – Performance enhancements of transmission control protocol over satellite networks
– Recommendation ITU-R S.1716 – Performance and availability objectives for fixed-satellite service telemetry, tracking, and command systems
– Recommendation ITU-R S.1855 – Alternative reference radiation pattern for earth station antennas used with satellites in the geostationary-satellite orbit for use in coordination and/or interference assessment in the frequency range from 2 to 31 GHz
– Recommendation ITU-R S.1856 – Methodologies for determining whether an IMT station at a given location operating in the band 3 400-3 600 MHz would transmit without exceeding the power flux-density limits in the Radio Regulations Nos. **5.430A**, **5.432A**, **5.432B** and **5.433A**
– Recommendation ITU-R BO.652-1 – Reference patterns for earth station and satellite antennas for the broadcasting satellite service in the 12 GHz band and for the associated feeder links in the 14 GHz and 17 GHz bands
– Recommendation ITU-R BO.792 – Interference protection ratios for the broadcasting-satellite service (television) in the 12 GHz band
– Recommendation ITU-R BO.1213-1 – Reference receiving earth station antenna pattern for the broadcasting-satellite service in the 11.7-12.75 GHz band
– Recommendation ITU-R BO.1293-2 – Protection masks and associated calculation methods for interference into broadcast-satellite systems involving digital emissions
– Recommendation ITU-R BO.1773 – Criterion to assess the impact of interference to the broadcasting-satellite service from emissions of devices without a corresponding frequency allocation in the Radio Regulations, that produce fundamental emissions in the frequency bands allocated to the broadcasting satellite service
– Recommendation ITU-R BO.1776-1 – Maximum power flux-density for the broadcasting-satellite service in the band 21.4-22.0 GHz in Regions 1 and 3
– Recommendation ITU-R BO.1898-1 – Power flux-density value required for the protection of receiving earth stations in the broadcasting-satellite service in Regions 1 and 3 from emissions by a station in the fixed and/or mobile services in the band 21.4-22 GHz
– Recommendation ITU-R BO.1900 – Reference receive earth station antenna pattern for the broadcasting-satellite service in the band 21.4-22 GHz in Regions 1 and 3
– Report ITU-R M.2109 – Sharing studies between IMT Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3 400-4 200 and 4 500-4 800 MHz frequency bands
– Report ITU-R S.2199 – Studies on compatibility of broadband wireless access (BWA) systems and fixed-satellite service (FSS) networks in the 3 400-4 200 MHz band
– Report ITU-R BO.631-4 – Frequency sharing between the broadcasting-satellite service (sound and television) and terrestrial services

– Report ITU-R BO.634-4 – Measured interference protection ratios for planning television broadcasting systems

# Annex 4

## Studies on Cognitive Radio Systems in Europe

### Published deliverables

CEPT studies relating to technical and operational requirements for operation of White Space Devices (WSDs) in the frequency band 470-790 MHz are presented in the following reports: ECC Report 159 [1]; ECC Report 185 [2] and ECC Report 186 [3].

ETSI has published EN 301 598 V1.1.1 (2014-04) on Wireless Access Systems operating in the 470 MHz to 790 MHz.

CEPT/ECC has published ECC Report 236 on guidance for national implementation of a regulatory framework for TV WSD using geolocation databases in 2015.

ECC has not adopted nor planned to adopt a harmonisation measure concerning the possible use of the band 470-790 MHz by WSDs.

The incumbent radio services/systems considered in the technical studies, with a summary of these reports, are presented below:

### Incumbent radio services/systems

The protection of the following incumbent radio services/systems is analysed in the reports mentioned above:

− Terrestrial Broadcasting Service (BS) including DVB-T in particular.

− Program Making and Special Event (PMSE) systems including radio microphones in particular.

− Radio Astronomy Service (RAS) in the 608-614 MHz band.

− Aeronautical Radio Navigation Service (ARNS) in the 645-790 MHz band.

− Mobile Service (MS) below 470 MHz and above 790 MHz.

### Summary of the above mentioned ECC Reports

The ECC Report 159 [1], as the starting point of the investigations on CRS, carried out studies on the compatibility of WSD with some of the incumbent radio services/systems listed above. These studies were focussed on stand alone, sensing based WSD. This report concluded a list of areas requiring further work, summarized as follows:

− Areas related to WSD characteristics.

− Technical considerations on the protection of the broadcasting service.

− Technical considerations on the protection of PMSE.

− Specification and implementation of the requirements for the geo-location database approach.

In following to this, the output of the ECC Report 185 [2], which complements the analysis of the ECC Report 159 [1], is as follows:

a) Classification of White Space Devices (WSD) and possible approaches to set up fixed maximum permitted power limits for WSDs.

b) Considerations on the collaborative spectral sensing to overcome site-specific bad channel conditions.

c) Protection of broadcasting: Complementary analysis on the sensitivity of the basic parameters (location probability, coverage assessment) and the performance of DTT receivers in the presence of WSDs.

d) Protection of PMSE.

e) Protection of ARNS.

f) Impact of WSD interference on mobile services operating in adjacent bands to 470-790 MHz.

g) Some Examples of national investigations on spectrum potentially available for WSDs.

As a completion of the ECC Report 185 [2], the ECC Report 186 [3] was developed to analyse the technical and operational requirements for the operation of WSD under the geo-location database, namely:

a) Considerations on location accuracy of WSD.

b) General principles and operational requirements to WSD operating under the master/slave concept.

c) Database management.

d) Examples of the translation process in the geo-location database to protect incumbent radio services/systems.

e) Considerations on the combination of sensing and geo-location.

It should be noted that these reports are mainly for guidance for administrations within the CEPT possibly planning to introduce cognitive radio systems within the frequency range 470-790 MHz on a national basis.

It should also be noted that a harmonization of the requirements of the geo-location database and its interfaces is in progress within the framework of ETSI.

# Annex 5

## Studies conducted by the Russian Federation on temporarily unused/unoccupied spectrum in the bands allocated to the broadcasting service

This Annex contains methodology to quantify temporarily unused/unoccupied spectrum as well as analysis of one of the scenarios of implementation for cognitive radio systems. It is based on the studies conducted by the Russian Federation.

The frequency band 470-790 MHz is widely used by the broadcasting service and is the main frequency resource for the implementation and development of digital terrestrial broadcasting in the Russian Federation.

An assessment of the available frequency spectrum as white space in the Russian Federation within digital TV terrestrial broadcasting has been carried out for the Arkhangelsk region. This assessment did not take into the use of this spectrum by ARNS systems (645-790 MHz), by services auxiliary to broadcasting (SAB/SAP), cable broadcasting systems and, in some instances, by analogue TV broadcasting stations.

**Methodology to quantify temporarily unused/unoccupied spectrum**

The following assumptions were made regarding the methodology used to assess the amount of available spectrum for White Space Devices (WSDs):

– Simultaneous use of 470-694 MHz by broadcasting service and white space devices was considered;

– The 1% degradation of location probability of digital television was chosen as a criterion of availability;

– WSDs are assumed to be mounted at 30 m above ground;

– Worst case protection ratios from Recommendation ITU-R BR.1368 for LTE interference were used (protection of 90% of silicon tuners and 0% payload option for WSDs);

– Propagation model: free space and standard deviation of 3.5 dB for distances up to 80 m, Recommendation ITU-R P.1546 and standard deviation of 5.5 dB for longer distances;

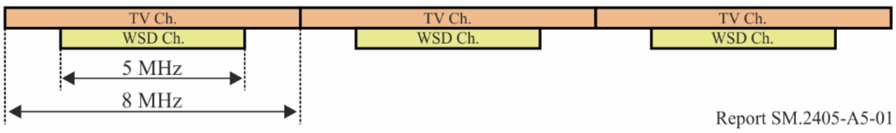
– The summation of interfering signals was not taken into account;

– Directivity discrimination of receiving antenna was considered at each point;

– The 5 MHz bandwidth for WSDs channel was considered and WSDs channels were allocated in such a way that centre frequencies of WSD channels coincided with centre frequencies of TV channels (see Fig. A5-1).

FIGURE A5-1

**TV and WSD channel grid**



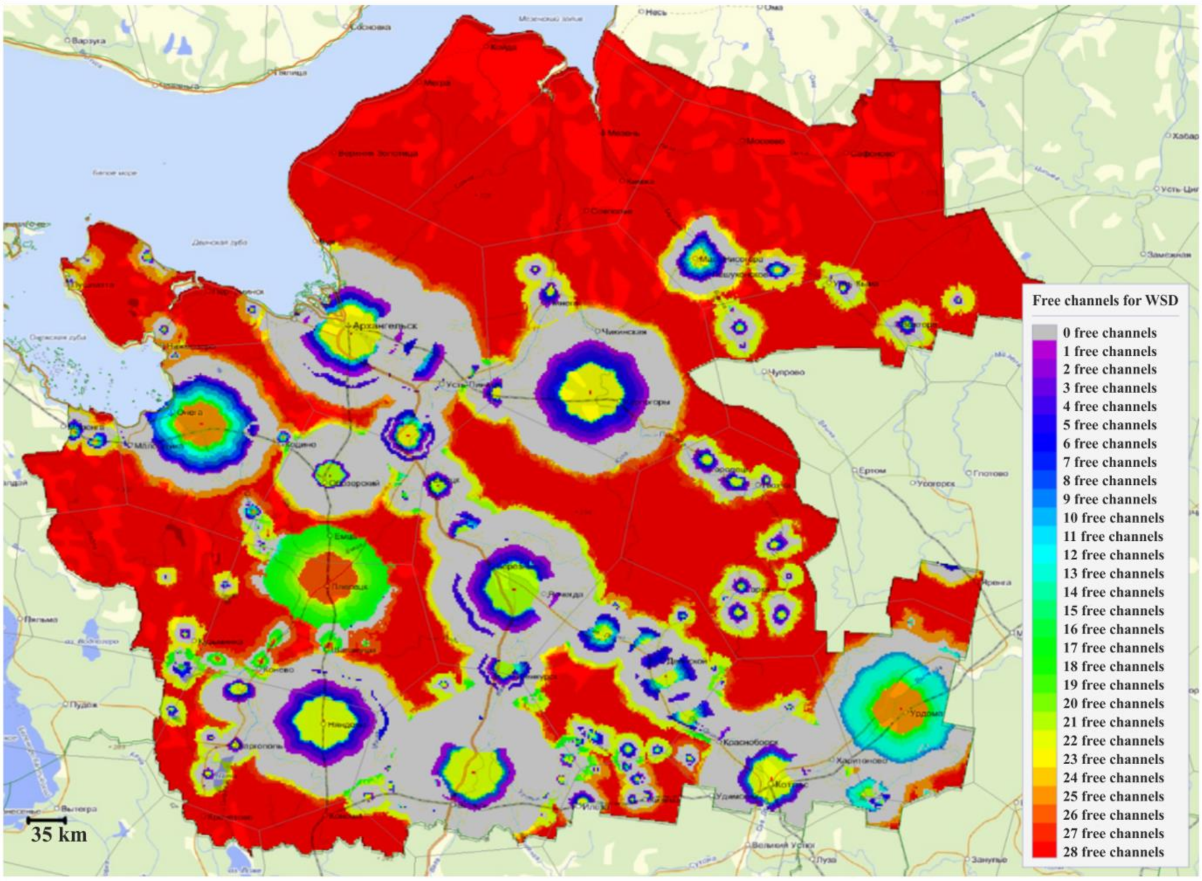

**Estimation of available spectrum**

The map with an amount of spectrum available across the region is presented in Figure A5-2 for an e.i.r.p. of 20 dBm. The region is characterized by a uniform relief and low density of television stations and settlements, especially in its northern part.

Figure A5-3 presents the dependence of the number of free channels for cognitive device on the percentage of the region territory for which this amount of free channels is available. Figure A5-4 presents the dependence of the number of free channels on the percentage of population living in the region, for which this amount of free channels is available.

FIGURE A5-2

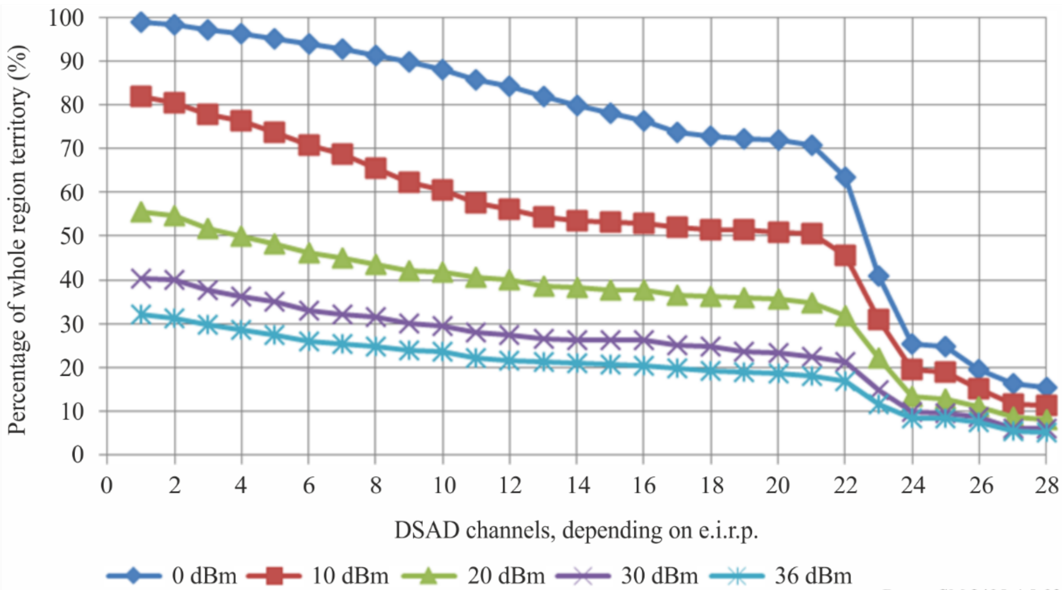
**Example of the map of frequency spectrum availability for WSDs with power 20 dBm (100 mW) for Arkhangelsk region**




Report SM.2405-A5-02

FIGURE A5-3

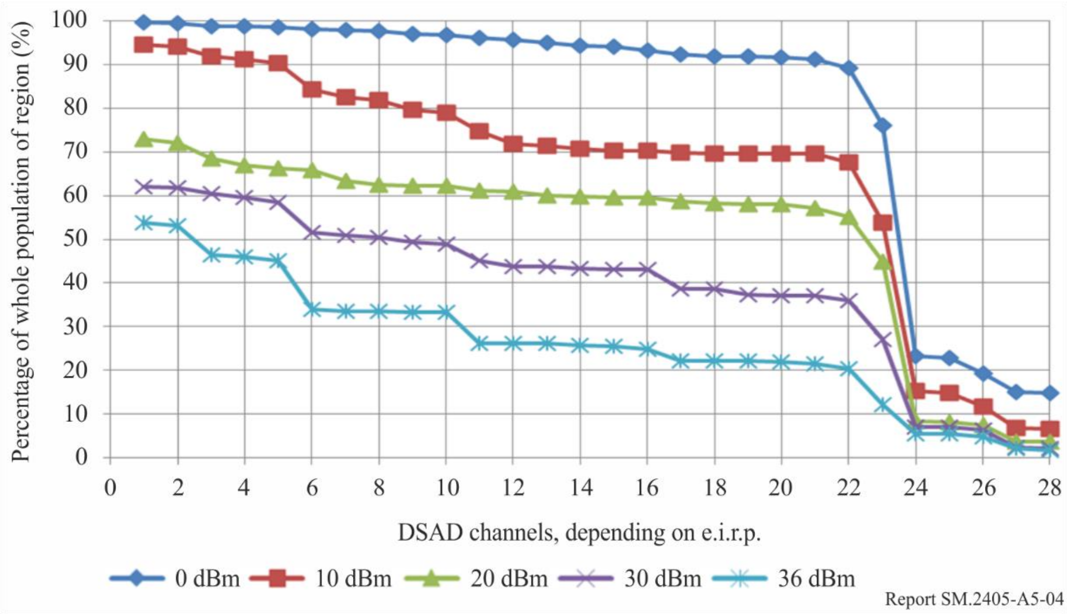
**The results of analysis of available dynamic spectrum allocation channels for WSDs depending on the % pixels, for which this amount of free channels is available**




Report SM.2405-A5-03

FIGURE A5-4

**The results of analysis of available dynamic spectrum allocation channels for WSDs depending on the % of population of the region, for which this amount of free channels is available**




The estimation of available spectrum for implementation of WSDs was carried out in one region of Russian Federation. Results of calculations show that with low power WSDs (e.i.r.p. 0 dBm) 20 channels are available for 90% of the regional population, but with high power WSDs (e.i.r.p. 36 dBm) 20 channels are available only for 20% of the regional population. And these settlements (which constitute 20% of population) are situated near the TV stations.

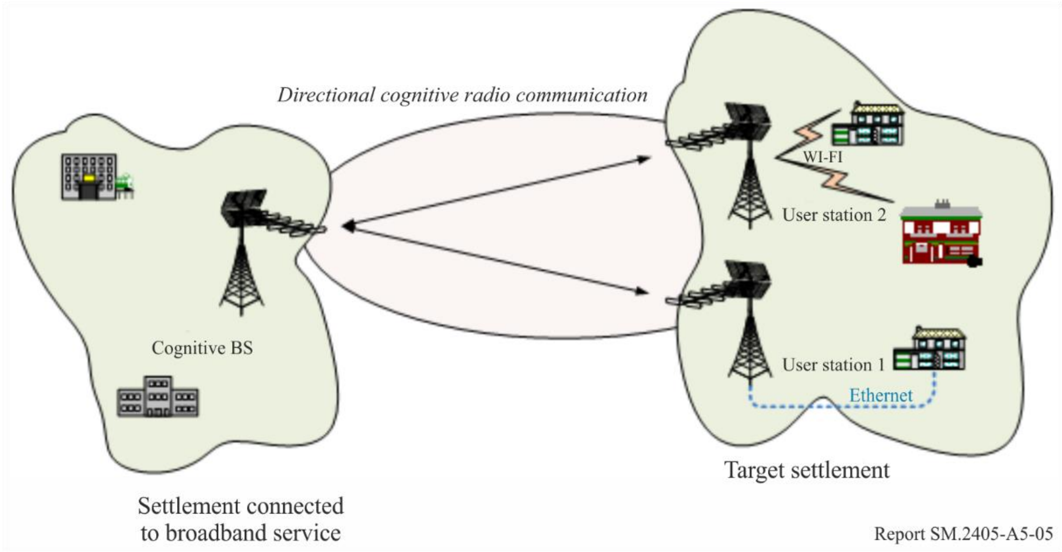
It needs to be noted that the calculations presented did not consider aggregated interference from multiple WSDs, which could decrease an amount of available spectrum for WSDs.

**Application scenarios for point-to-point (P-P) radio communication link**

There are many smaller settlements in the Russian Federation where broadband access is unavailable. Typical implementation scenario for cognitive radio communication system in this case is to deploy the headend in a settlement with fixed broadband Internet access, while user stations are deployed in a remote settlement. In this case both headend and remote stations could use directional antennas (see Fig. A5-5).

FIGURE A5-5

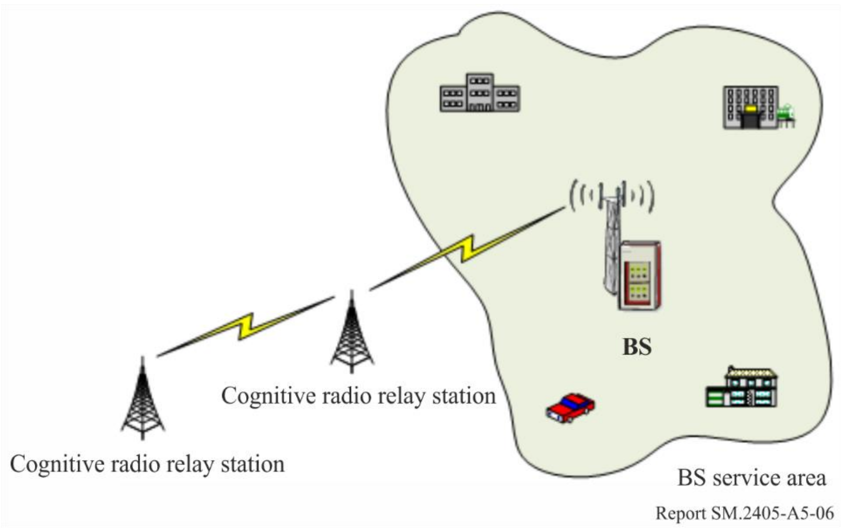
**Inter-settlement P-MP link using directional antennas in the frequency band 470-686 MHz**




And within the settlement small LTE BSs (micro cells) or broadband Wi-Fi hotspots could be deployed as user stations of cognitive radio system. Such a topology would allow resident connection to the public networks via standard radio interfaces of off-the-shelf subscriber devices, while using unoccupied spectrum in the band 470-790 MHz for the communication. Figure A5-6 shows a multi-hop radio link based on cognitive radio system.

FIGURE A5-6

**Inter-settlement radio relay link based on cognitive technology**




An advantage of this option is that there is no need in the specific telecom operator. Similarly to the license-exempt radio systems, either users themselves or an authorized company responsible for CRS installation and operation pursuant to the rules of CRS installation and operation in the Russian Federation.

To ensure interference-free operation of protected primary radio systems in the broadcasting band, highly directional antennas and permissible values of radiated power should be applied. Table A5-1 provides examples of calculated distances for P-P and P-MP radio links using low-power and medium-power transmitters and Yagi directional antennas, similar to those applied for reception of terrestrial TV broadcasting in the frequency band 470-790 MHz.

TABLE A5-1

**Example of inter-settlement distance calculation for broadband access/radio relay link in the frequency range 600 MHz using fixed antennas such as applied in TV broadcasting**

The calculation was carried out for modulation parameters similar to those used in DVB-T2

| Parameter | Low-power long range | Low-power mid-range | Low-power short range | High-power long range | High-power mid-range | High-power short range |
|---|---|---|---|---|---|---|
| Transmitter power (W) | 1 | 1 | 1 | 25 | 25 | 25 |
| Antenna gain (dBd) | 12 | 12 | 10 | 12 | 12 | 10 |
| Antenna height (m) | 10 | 10 | 10 | 10 | 10 | 10 |
| Feeder losses (Db) | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| e.r.p. (dBW) | 9.5 | 9.5 | 7.5 | 23.5 | 23.5 | 21.5 |
| Modulation | QPSK | 64-QAM | 256-QAM | QPSK | 64-QAM | 256-QAM |
| Code rate | ¾ | ½ | ¾ | ¾ | ½ | ¾ |
| Capacity (Mbit/s) | 11 | 22 | 44.3 | 11 | 22 | 44.3 |
| Minimum field strength for 70% locations (dB(μV/m)) | 35.6 | 42.0 | 51.8 | 35.6 | 42.0 | 51.8 |
| Maximum distance for moderately rugged terrain Rec. ITU-R P.1546-4 | 6.8 | 5.0 | 2.8 | 13.6 | 9.9 | 5.7 |
| Maximum distance for LoS path Rec. ITU-R P.1812-2 | 9.1 | 6.6 | 5.2 | 33 | 20.1 | 14.7 |

Reduction of interference to the TV broadcasting in the 470-790 MHz frequency band during installation and tuning of CRS is required to be ensured, that could be achieved by the following measures:

– Optimization of location and pointing of CRS antennas;
– Reduction of CRS radiated power;
– Forced prohibition to use certain radio channels for installed CRS despite the permission obtained from CR ACS (geolocation database);
– Insertion of additional frequency-selective filters at the output of CR transmitter.

Using these on-site mitigation measures, maximum possible effect could be achieved in difficult cases, for example, in the far part of TV service area or in penumbra region where a level of received terrestrial TV broadcasting signal is relatively low. Only such installation method would provide best conditions for ensuring EMC with TV broadcasting.

To confirm viability for the territory of Moscow District field tests were carried out. To protect TV broadcasting, noise immunity of the digital modulation system, corresponding to COFDM 64-QAM in the 8 MHz channel bandwidth, were taken as the basis. Table A5-2 shows minimum field strength for TVCH 40.

TABLE A5-2

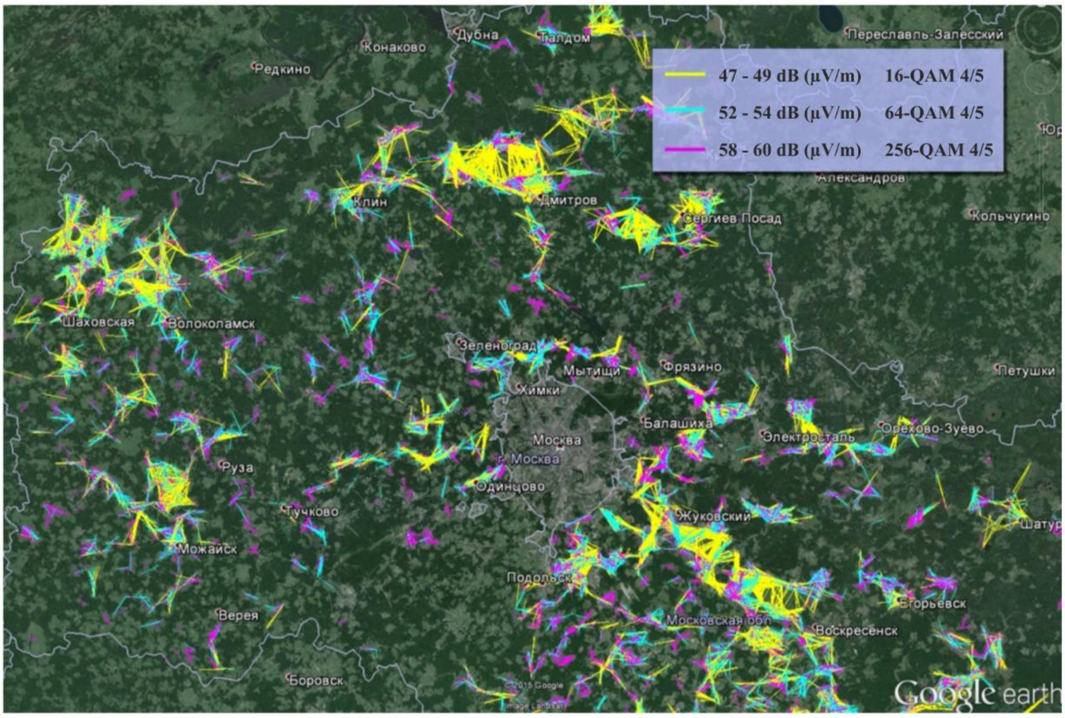
**Minimum median field strength of DVB-T2 for TVCH 40**

| | **$E_{min}$, dB(μV/m)** | | |
|---|---|---|---|
| Percentage of locations | 50% | 70% | 95% |
| QPSK (with code rate 4/5) | 32.3 | 35.2 | 41.4 |
| 16-QAM (with code rate 4/5) | 38.4 | 41.3 | 47.5 |
| 64-QAM (with code rate 4/5) | 44.0 | 46.9 | 53.0 |
| 256-QAM (with code rate 4/5) | 49.4 | 52.3 | 58.4 |

Figures A5-7 and A5-8 represent potential paths (with different colours) for measurements. Modelling is performed according to the prediction method for P-P paths described in Recommendation ITU-R P.1812. Additional calculations were also performed using methodology described in Recommendation ITU-R P.1546. The simulation was performed taking into account the natural obstacles in path and forests clutter.

FIGURE A5-7

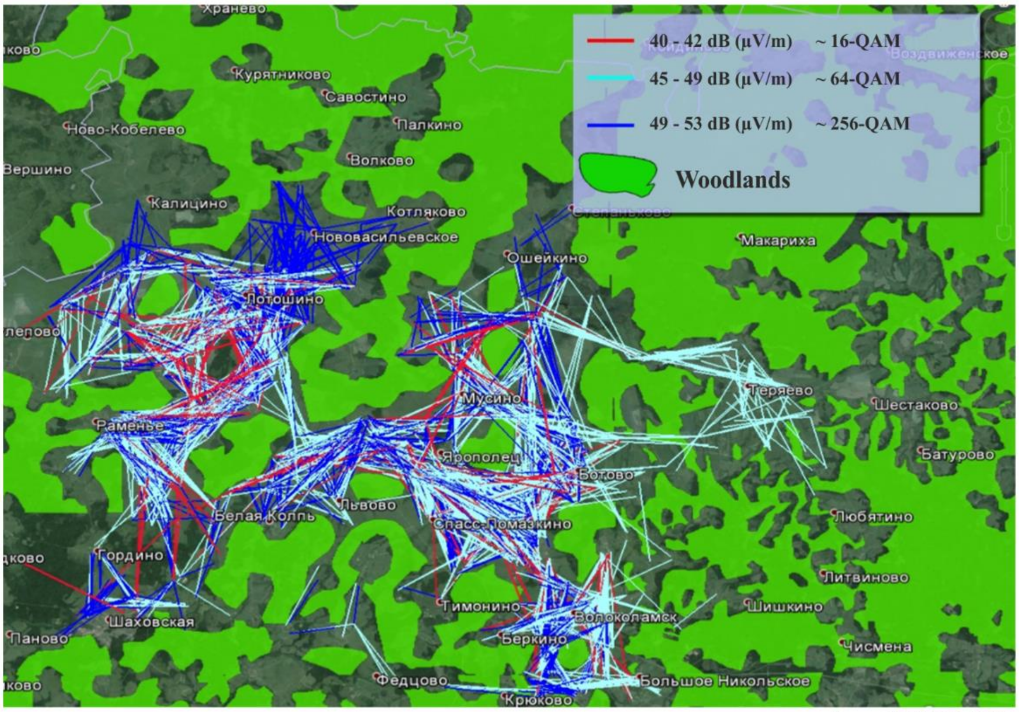
**Potential paths for inter-settlement communication in Moscow District**




Report SM.2405-A5-07

FIGURE A5-8

**Potential paths for field tests in Moscow District**

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Field tests were performed, revealing sufficient signal levels in most calculated locations with low transmit/receive antenna height (10 m). According to the measurements, maximum achievable data transmission speed is 48.27 Mbit/s (corresponds to 256-QAM 4/5) for 8 MHz radio channel bandwidth. A distance between these settlements is 8.6 km along the half-closed path. Minimum data transmission speed is 18.07 Mbit/s (corresponds to 16-QAM 3/5), obtained for inter-settlement communication radio link for the distance between settlements 11.1 km, along the half-closed path.

The measurements have shown that one of the main conditions for assured reception is the percentage of non-LoS due to obstacles in the propagation path. All paths with percentage of LoS zone more than 50%, essential for propagation, provided assured reception of a signal. Other paths with more NLoS percentage between transmit and receive sites, mostly did not provide reception. Hence, such characteristics of cognitive radio system as the range and achievable data transmission speed could vary depending on the clutter's type.

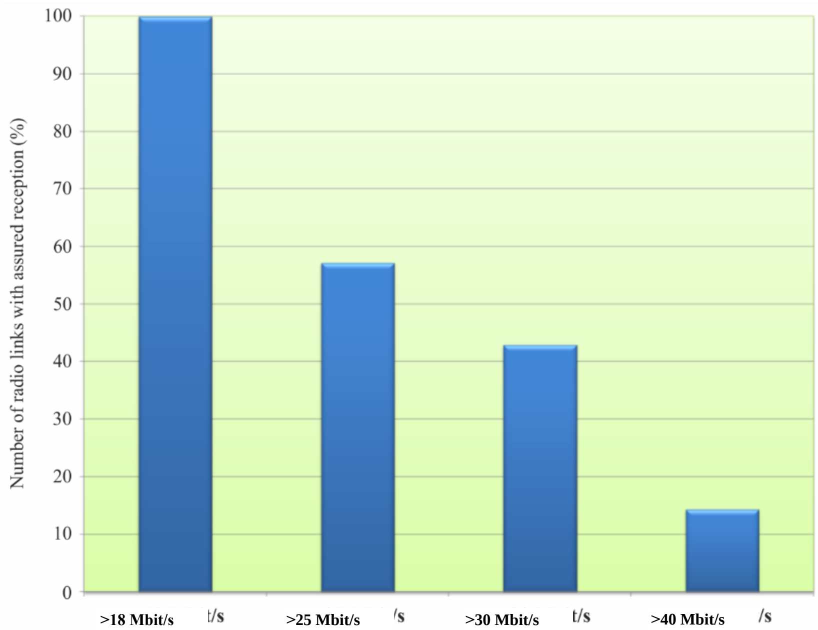
Figure A5-9 shows the diagram reflecting distribution of maximum achievable data transmission speeds within the 8 MHz radio channel bandwidth. Diagram columns cover four ranges of data transfer rates:

1) more than 18 Mbit/s
2) more than 25 Mbit/s
3) more than 30 Mbit/s
4) more than 40 Mbit/s.

The diagram presents analysis of all possible paths between settlements on the example of Moscow District taking into account path profile (clutter type).

FIGURE A5-9

**Number of radio links versus maximum achievable data transfer rates**

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The number of radio links with ensured data rates more of than 40 Mbit/s is nearly 14%, while data rates of 25-30 Mbit/s in average are available for 50% of radio links. Such average data rate is achieved at distances from 8 to 12 km.

Possible technical parameters WSD terminal stations are listed in Table A5-3.

TABLE A5-3

**Technical parameters WSD**

| Parameter | Minimum value | Maximum value |
|---|---|---|
| Transmitter power (W) | 0.1 | 25 |
| Antenna gain (dBd) | 5 | 14 |
| Antenna height (m) | 10 | 30 |
| Feeder losses (dB) | 1 | 5 |
| e.r.p. (dBW) | 8 | 27 |

Thus based on the results of the studies conducted by the Russian Federation, the following can be concluded:

1) The TV broadcasting frequency band has an unoccupied frequency resource which amount substantially depends on the territory and characteristics of cognitive radio systems.

2) The unoccupied spectrum in the broadcasting band can be used by P-P systems with dynamic access to the resource based on the geolocation database, with possible up to 40 Mbit/s data rate at distances up to 10-12 km for LoS paths between settlements for average conditions and up to 18 km for LoS paths for interference-free reception by TV broadcasting. However special measures should be taken to exclude cases of unintended interference to TV broadcasting reception, specifically, preliminary network planning.

# Annex 6

## Researches on dynamic spectrum access by cognitive radio in China

Because the technique of dynamic spectrum access by cognitive radio is a feasible solution for the shortage of spectrum resources and the spectrum inefficiency, research work on spectrum management for DSA technique is making progress in China, and trial networks of DSA systems are deployed in band 223-235 MHz, for the further development of the technologies of DSA system and spectrum management.

### Spectrum allocation in band 223-235 MHz

In China, the spectrum resources in band 223-235 MHz were allocated to industries, such as energy industry and mining industry for data transmission. Different spectrum resources were statically allocated to industries in the whole country. Industry applications are using data transceivers primarily for data transmission, and the deployment of data transceivers for industry applications must be approved and registered by the spectrum regulator.

### Spectrum inefficiency in band 223-235 MHz with static spectrum allocation

The static spectrum allocation causes spectrum inefficiency in band 223-235 MHz.

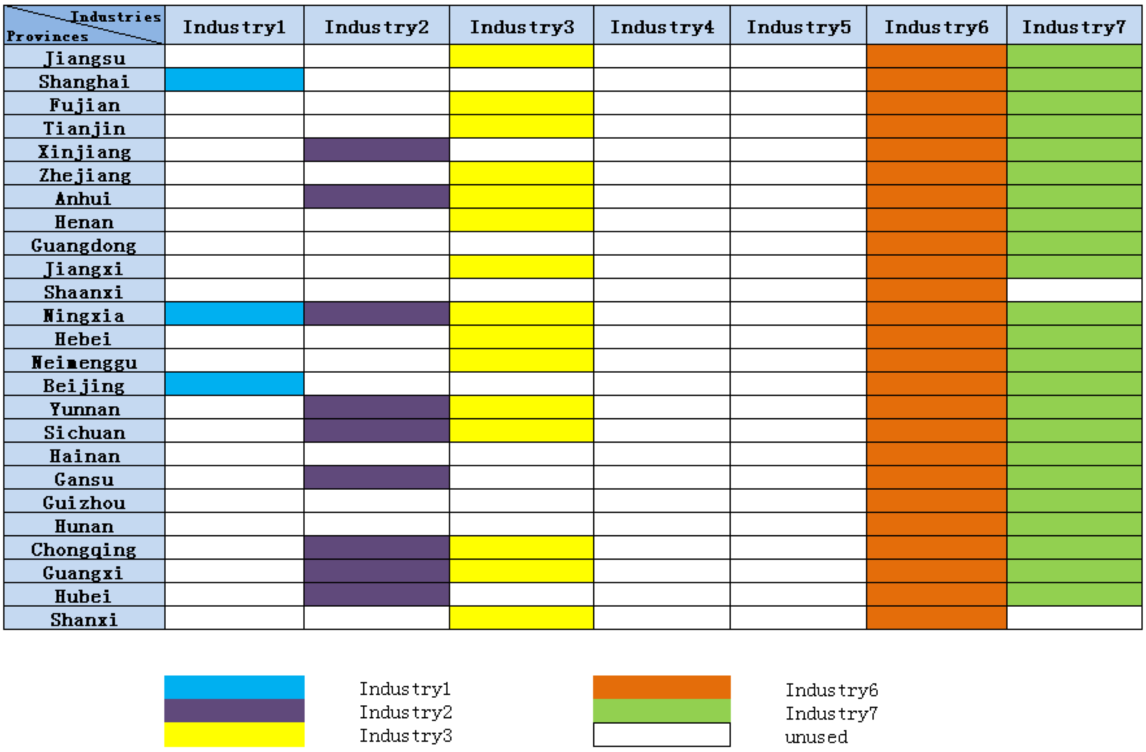
(1) Because of the characteristics of industry applications, the application data is only needed to be transmitted periodically. Very often, the spectrum resources allocated to some industries are in temporarily unused state. With the static spectrum allocation, these unused spectrum resources cannot be used by other industries.

(2) With the current static spectrum allocation, in any geographical area, the spectrum resources allocated to one industry cannot be used by other industries. However, some industries may not even exist in certain regions, so there is no data transmission at all in the spectrum allocated to those industry applications. But these unoccupied spectrums cannot be used by other industries, with the static spectrum allocation.

Table A6-1 shows the spectrum utilization of band 223-235 MHz allocated to some industries in different provinces. In the table, the coloured cell means the spectrum allocated to the industry is used in this province or city and the blank cell means the spectrum is unused. From Table A6-1, we can find that the spectrum resources allocated to some industries are not used in some regions.

TABLE A6-1

**Spectrum utilization of band 223-235 MHz allocated to some industries in provinces**




### Increasing spectrum requirements for industry development

With the industry development, such as Smart Grid and Intelligent Oil Fields, the characteristics of the industry applications have been changed, and more spectrum resources are required for application data transmission. But in band 223-235 MHz, there are not enough spectrum resources to meet the increasing spectrum requirements of industry applications.

### Application of DSA by CR in band 223-235 MHz

In band 223-235 MHz, how to improve the spectrum efficiency is becoming very important. Application of DSA system in band 223-235 MHz is under consideration, and with cognitive radio technique, the temporarily unused/unoccupied spectrum can be detected and shared among industries. Accordingly, the spectrum efficiency in band 223-235 MHz is improved and the spectrum requirements of industries could be met as well.

### Spectrum management challenges

With the application of dynamic spectrum access by cognitive radio in band 223-235 MHz, new challenges to spectrum management arise:

(1) Guarantee the reliable and real-time transmission of cognitive information

The DSA system should be able to determine the temporarily unused/unoccupied spectrum correctly with the reliable and real-time transmission of cognitive information. And for radio communication systems, the control information, such as communication channel setting, must be transmitted correctly.

In the DSA system, when the data is transmitted with the shared spectrum, it should be considered that how to guarantee the reliable and real-time transmission of the cognitive information or the control information.

(2) Guarantee the quality of service

Data of different services has different quality of service (QoS) requirements, e.g. strict latency requirement for some important service data. With the application of the DSA system, it should be considered that how to guarantee the QoS of the important service data.

In the incumbent non-DSA system, the control information and the service data are transmitted with the spectrum resources allocated statically. However, with the introduction of DSA system, the resources allocated to the incumbent systems can be dynamically detected and used by a DSA system, and the incumbent system might be interfered. Accordingly, the transmission of the control information and service data of the incumbent system will be interrupted, and their QoS cannot be guaranteed.

Because there are more than one system in the operating frequency band, a DSA system might operate on the frequency adjacent to other DSA or non-DSA systems. Therefore, the compatibility between systems operating on the same frequency band should be realized to avoid the interference and guarantee the QoS of different systems.

(3) Guarantee the spectrum fairly shared among systems

For multiple DSA systems might operate at the same time, the scheme should be designed to guarantee the shared spectrum resources to be obtained fairly among the systems in terms of resource usage time and resource amount.

**Spectrum management research work being carried out**

Currently, the research work on spectrum management and spectrum engineering techniques has been carried out to solve the problems mentioned above, mainly focusing on the following areas:

– Spectrum planning for the application of DSA systems

In order to guarantee the reliable and real-time transmission of the cognitive information or the control information of systems, the proper spectrum resources should be allocated to them and the protection criteria of these resources should be properly designed.

– Making rules for resources used among DSA systems

In order to guarantee the quality of service (QoS) requirements of service data and the resources to be shared among DSA systems fairly, the rules for shared resources utilization should be developed, such as, setting the allowed maximum usage time and quantity of shared spectrum resources for each DSA system at one time.

– Standardization for operational and technical characteristics of DSADs

Some operational and technical characteristics of DSADs should be standardized to realize the compatibility between systems in the operating band, such as, RF requirements, Detection Probability, and Back off Time.

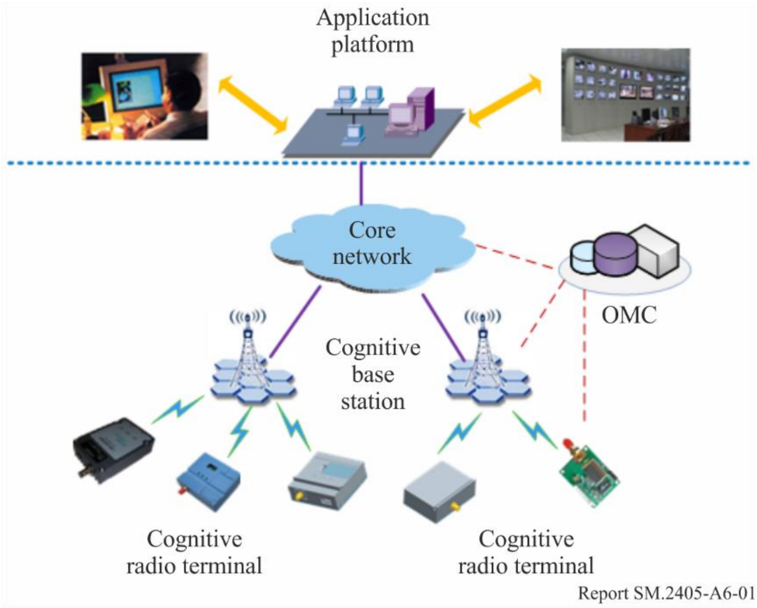
**Trials on DSA in electricity industry**

The DSA system by cognitive radio for trial has been developed in band 223-235 MHz, and the architecture of it is given in Fig. A6-1. The system is composed of Wireless Access Network, Corn

Network (CN), Operation and Maintenance (OMC) and Application Platform. Wireless Access Network includes Cognitive Base Stations and Cognitive Radio Terminals, which are used for the detection of temporarily unused spectrum resources. Application Platform provides the function of statistics and analysis of application data.

FIGURE A6-1

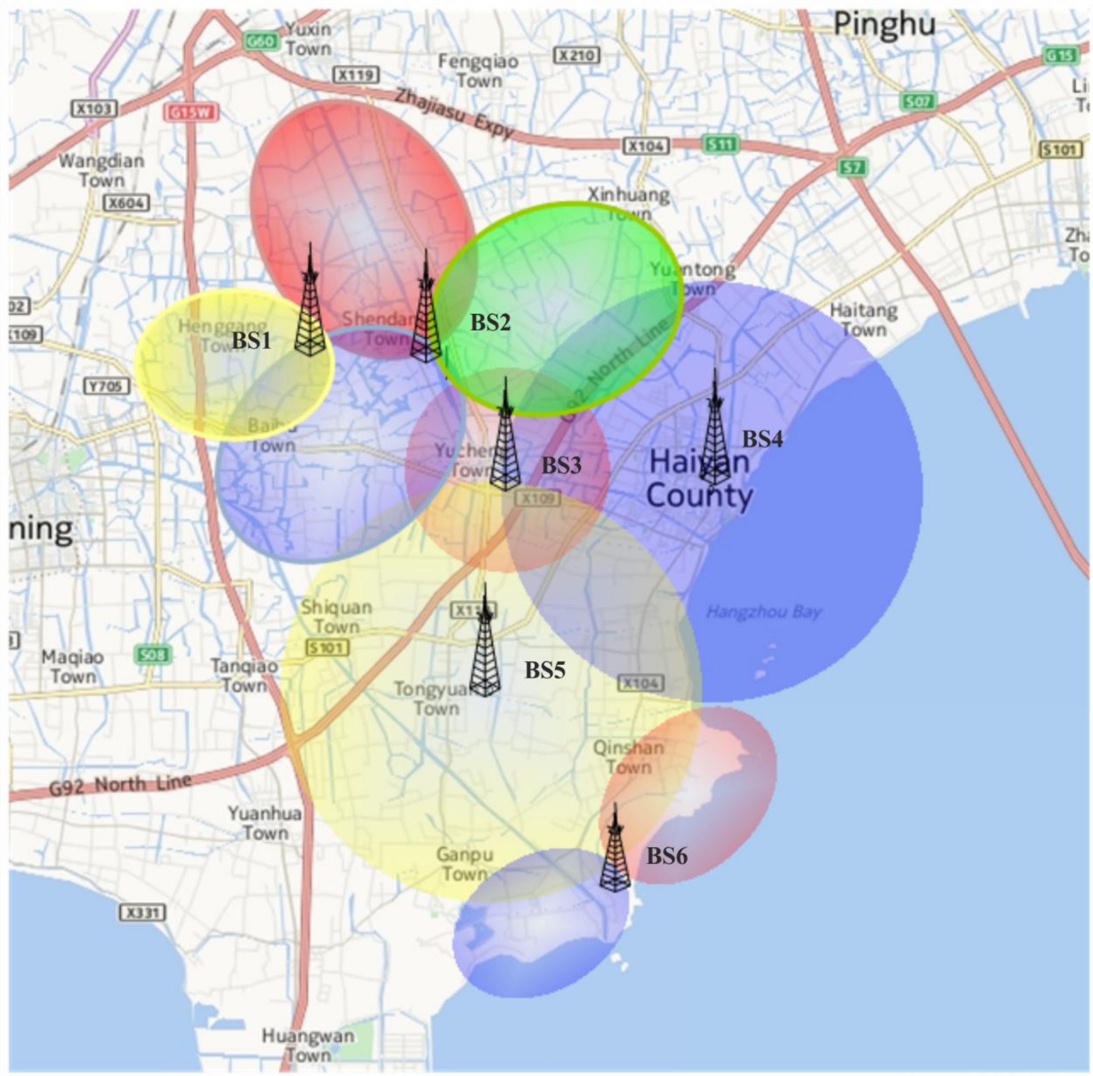
**Architecture of DSA system for trial**




With the construction and development of Smart Grid in China, more spectrum resources are required for the applications, such as power distribution automation and power consumption information collection. But the spectrum resources allocated to electricity industry in band 223-235 MHz are not enough. Accordingly, in Zhejiang province in China, the DSA system by CR for trial was deployed for electricity industry, and with cognitive radio technique, the unused spectrum could be detected and spectrum requirement from the application of Smart Grid could be met. Figure A6-2 shows the trial network deployment in Haiyan, a county of Zhejiang province.

FIGURE A6-2

**Trial network deployment in Haiyan**




Report SM.2405-A6-02

The performance of DSA system can be verified on the trial network. According to the test results, the temporarily unused spectrum resources can be detected and used for electricity application based on the cognitive radio technique. And combined with Orthogonal Frequency Division Multiplexing (OFDM) and Adaptive Modulation and Coding (AMC) technique, the spectrum efficiency of band 223-235 MHz is improved significantly from 0.768 bps/Hz to 2.44 bps/Hz. In the future, the test will be further extended for spectrum sharing among multiple dynamic spectrum access systems for different industries.

# Annex 7

# ATDI experience for TVWS calculations

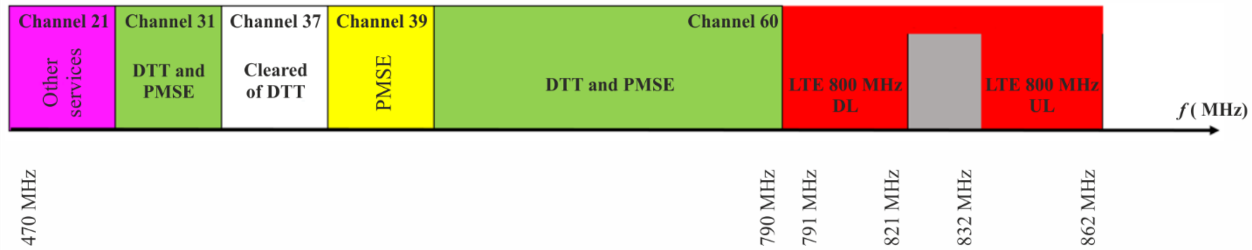
## 1 Introduction

TV White Spaces (TVWS) are vacant frequencies below 1 GHz made available for unlicensed use in some countries, at locations where spectrum is not being used by licensed services, mainly the broadcasting video service. The 470–790 MHz band is currently used in Europe by Digital Terrestrial Television (DTT) and Program Making and Special Events (PMSE).

The following text details methods to simulate coexistence of the White Space Device (WSD) and the DTT. It also presents how to build, use and share a WSD database from calculations and analysis made with ATDI platform.

FIGURE A7-1

**Illustrative UHF TV band (470-790 MHz) and its European users**




Report SM.2405-A7-01

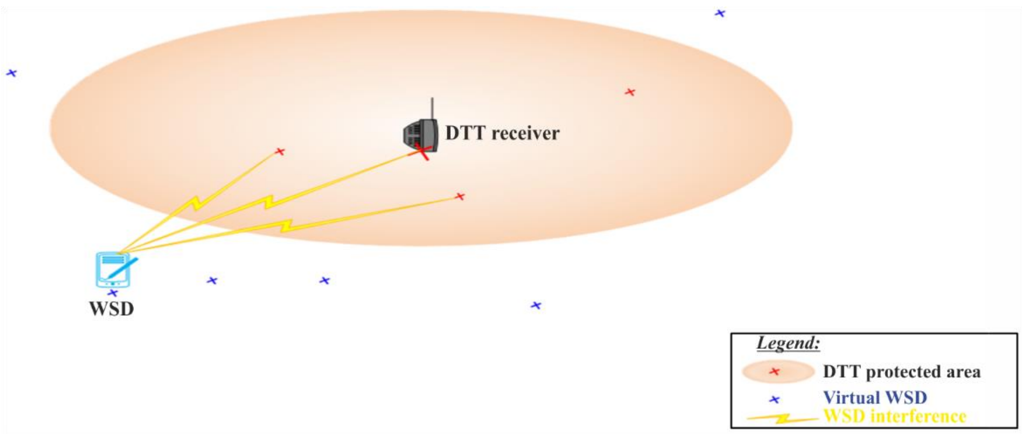
The same method as the one described below can be used to find available channels in any frequency band used by any radiocommunication service: change the settings of the calculations, defined by the user or retrieved from standard's tables; the same features can be used.

## 2 Approach to build a WSD national database

ATDI suggests performing the following tasks in order to build the WSD national database:

FIGURE A7-2

**Approach to build a WSD national database**




Report SM.2405-A7-02

a) Coverage calculation of all DTT networks. A deterministic propagation model is preferred for TVWS maps and interference calculation. This model is also used to check compatibility DTT and WSD.

The compatibility is checked on all receiving points inside the DTT coverage. If a DTT receiver is interfered by a WSD using its minimum power, then the location of the WSD is rejected.

b) Foreign DTT transmitters should also be taken into account. A method to protect foreign receivers (assignments and allotments) must be defined based on threshold and/or coverage calculation.

c) Definition of PMSE and other systems properties areas, designated channels…

d) Define possible reserved DTT channels (for possible future multiplex).

e) Check coverage and apply filter on populated areas using a population database.

f) Calculation of TVWS availability map using interference from WSD to DTT receivers to define exclusion areas. Calculations are made for a delta frequency up to n+/-3 channels (according to ETSI EN 301 598 V1.0.0, Table 3) and out of band domain, for each WSD class, for each DTT channel and for different WSD antenna heights. A noise margin can be applied in order to consider multiple WSD transmitting from the same point.

g) Make free spectrum maps available for online consultation (showing the number of available channels on each point) with the following information: coordinates of each point, channels available and associated maximum power allowed.

i) With the addition of number of new WSD, interference levels are re-checked with power sum of interference from new WSD aggregating to the DTT interference.

j) The WSD authorization ruling has also to be clearly defined: constraints by services, provisioning, priority…

k) Definition of authorized WSD protocols (open white-spaces) for distant router start-up and monitoring (QoS, Traffic).

## 3 Method overview for TVWS calculations

The main aim is to designate WSD frequencies in coverage gaps of TV channels. The method consists on identifying areas of availability of each TV channels.

To validate or invalidate the authorization, the method is detailed in the Figure below. The platform contains three key units:

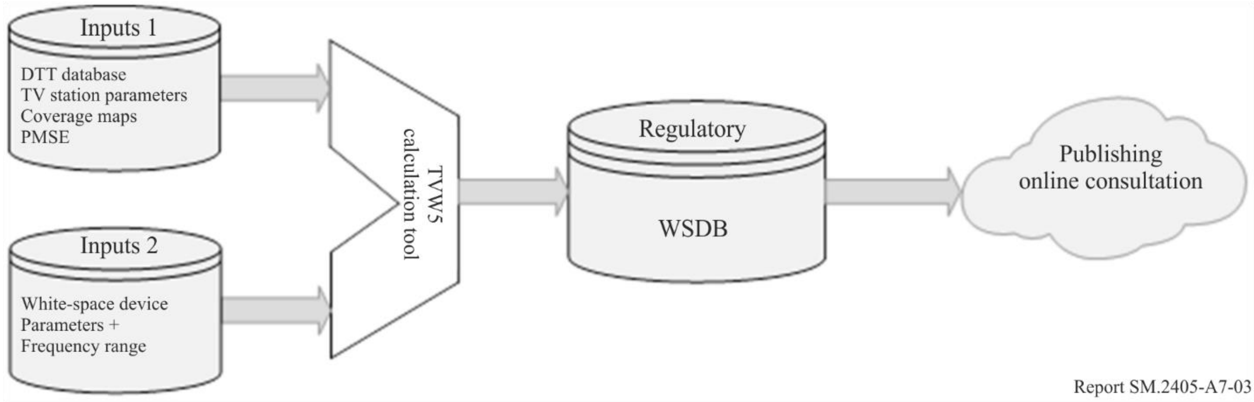
– A TVWS calculation tool.

– A management tool database.

– A publishing tool or a dedicated website.

FIGURE A7-3

**Platform overview for WSD management**




## 4 Implementation of TVWS calculation

### 4.1 TVWS calculation tool

A radio planning tool calculates and estimates from the database of existing DTT stations, the channels available on each point in a given area. Thus, to protect these areas (assignments and allotments) from any interference, based on the threshold and/or coverage calculation.

After this calculation, the necessary data is sent to backup and update the unlicensed WSD database (WSDB) for the next WSD requests.

The input data taken into account in this calculation is WSD parameters, frequency range and ID.

#### 4.1.1 Input data

The input data includes all parameters required for the calculations and the determination of TV white Spaces. This data consists of:

– The DTT and PMSE transmission parameters, site locations, coverage already computed...

– A request for WSD channel(s) with the known transmission parameters (power, dynamic range, frequency band...).

##### 4.1.1.1 DTT, PMSE stations database

This database contains all DTT stations and PMSE already allocated in a given area and at the national level. Thus, the characteristics (radiated power, coverage maps, location, frequencies, protection ratios...) of each known transmitter are available.

##### 4.1.1.2 WSD database

The WSD database (WSDB) contains the following information:

– Coordinates (longitude, latitude or X,Y) and antenna height or altitude of the master WSD.

– Power

– Antenna characteristics: gain, and polarization.

– Equipment class.

– The frequency band in which the WSD can operate.

This information is used to set up the calculation tool to perform the coverage of white space according to cartographic environment and clutter, propagation model and antenna height.

### 4.1.2 Proposed calculation method

The calculation, approved by the regulatory authority, builds the following:

– TVWS availability maps.

– Areas to be protected for each DTT channel.

– Assign channel(s) to WSD.

These calculations are performed for each DTT channel. It also provides the maximum allowed power for each channel and depends on the equipment class.

### 4.2 Database management tool WSDB

The results issued by the calculation tool are stored in the WSDB database, containing maps of protected channels, available TVWS channels, the maximum power allocated to each channel. It also registers the WSD already authorized.

The regulation authority will define the way to access to this database and the available channels allocation process. Online database management through a specific tool or a dedicated website will allow the sharing of the available channels according to the criteria defined by the regulator.

### 4.3 Online access

Once the WSDB database is filled, it can be shared online, to allow WSD users/operators to share information about available TVWS channels around a given area and provide a formal request for the use of a given WSD channel knowing:

– The eligibility, qualifications and priority of WSD channels from the type and the class.

– The list of available channels and the maximum power allocated.

– The list of already used channels (permanently or temporary such as for some PMSE services for example).

It is also possible to contact the database administrator to validate selected channels before using them. This web platform allows the operators to merge all channels requests performed from the WSD online registration forms and periodically forward them to the regulation authority.

## 5 The regulation authority

In the context of WSD management, the regulation authority defines the settings to be considered in the calculation tool. A number of rules can be recommended in order to enhance the performance and accuracy of the calculations. These settings allow compatibility between DTT and WSD.

Parameters to be considered:

– A reference propagation model.

– Coverage threshold and maximum distance calculation.

– Protection ratios for the DTT channel.

The regulation authority manages the database (maps of TVWS availability in given area, see Fig. A7-5) directly or indirectly through a "supra-operator". This WSDB administrator also defines the terms for TVWS channels’ allocation. For this the regulator may define a frequency allocation table also accessible online by users. The management of this table may be entrusted to the operator.

FIGURE A7-4

**Example of channels allocation table**

| | | Protection ratio *C/I* | | | |
|---|---|---|---|---|---|
| | | PR1 | PR2 | PR3 | PR4 |
| Priority | N1 | **C11** | C12 | C13 | C14 |
| | N2 | C21 | **C22** | C23 | C24 |
| | N3 | C31 | C32 | **C33** | C34 |
| | N4 | C41 | C42 | C43 | **C44** |

Report SM.2405-A7-04

An available TVWS channel corresponds to both a priority level (N) and a protection ratio *C/I* given. For example, a service with lower priority may be allocated a frequency only if there are more than two channels available at this point. See Figure A7-5 for an example of calculation of available TVWS in a given area.

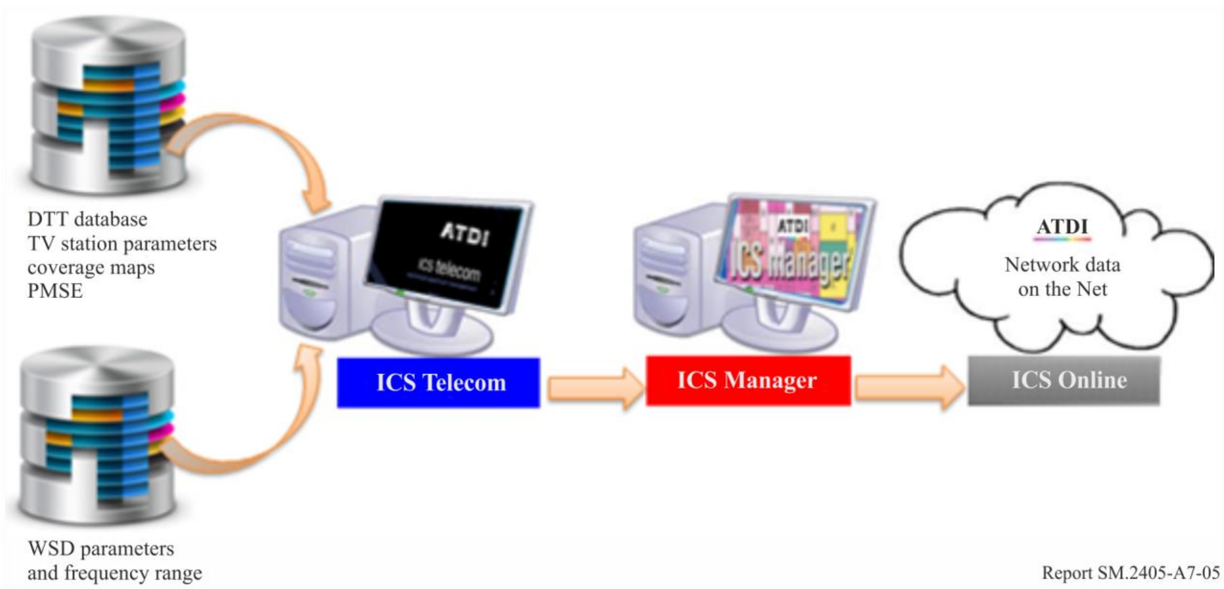
## 6 ATDI TVSW calculation platform

### 6.1 Overview

Based on the method previously described, the architecture of the ATDI platform to manage TVWS is described below.

FIGURE A7-5

**TVWS calculations and Management with ATDI tools**



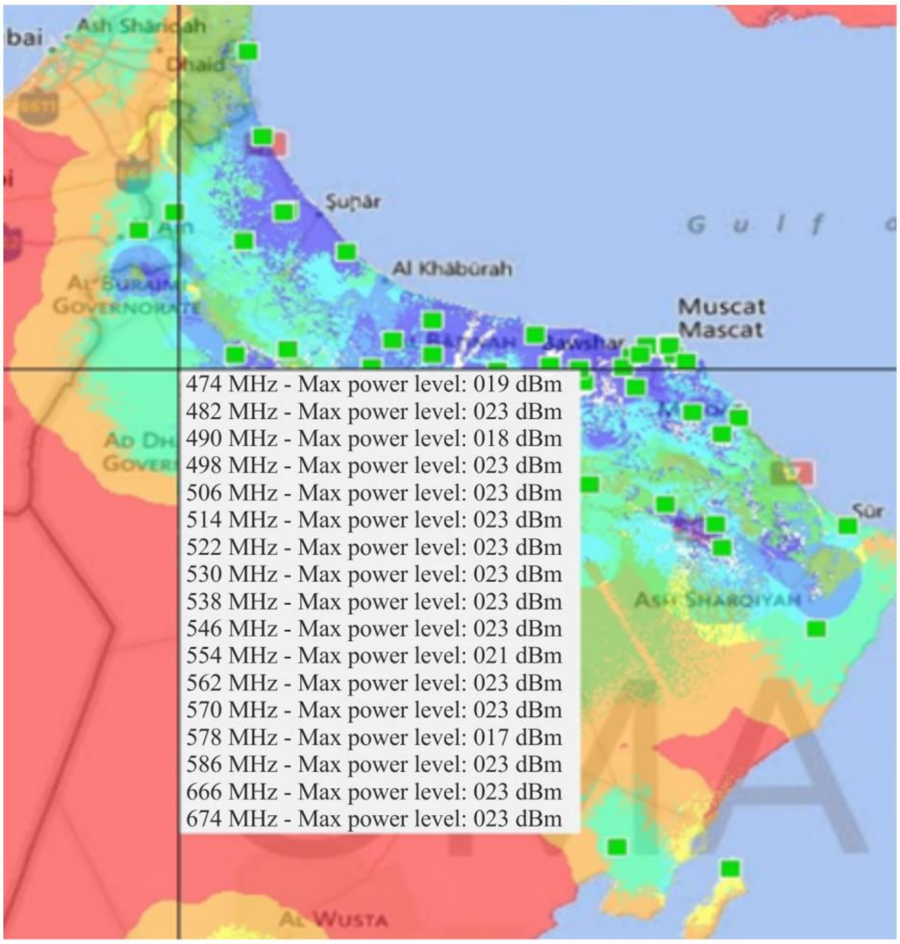

Report SM.2405-A7-05

ICS telecom is the radio planning tool developed by ATDI and used by many regulators and operators across the world. This computing platform henceforth includes dedicated modules to calculate TVWS.

For example, for a 100 000 km² map at a resolution of 100 m, the computing time is 15 min per channel with a typical 2017 PC.

FIGURE A7-6

**Available channels with the corresponding maximum power**




Report SM.2405-A7-06

The ATDI management system database, ICS manager, is dedicated to regulators and radio spectrum managers. This tool allows the allocation and administration of channels by establishing rules. ICS manager has an online service that allows sharing information with TVWS users. All these functions can be used for any type of technology.

## 6.2 Summary

The method proposed by ATDI allows to:

– Determine accurately the available TVWS channels, but not only. The same method can be applied to any service in any band, to identify the available channels.

– Allocate channels taking into account the rules for protected areas.

– Analyse the impact of a new deployment WSD on other services in a given area.

For further information about the tools developed by ATDI for the calculation and management of TVWS you can visit our website: [http://www.atdi.com/white-space-device-calculation-and-database/](http://www.atdi.com/white-space-device-calculation-and-database/).

# Annex 8

# Case studies in Botswana

## 1 Introduction

Health clinics in many developing countries lack adequate access to broadband. To tackle this health challenge in Botswana, the Botswana Ministry of Health and Botswana Communications Regulatory Authority (BOCRA) have partnered with the Botswana Innovation Hub (BIH), the University of Botswana, the U.S. Agency for International Development (USAID), the University of Pennsylvania, Microsoft, and Global Broadband Solutions (GBS) and launched a pilot project to deliver online health care service to regions in Botswana without access to broadband and adequate specialized health services. Broadband is delivered utilizing Dynamic Spectrum Access (DSA) over unused spectrum across television channels, or what is commonly referred to as TV White Space or TVWS.

Because this pilot highlights an example of shared spectrum access in a way that contributes to the health sector, this contribution is submitted to help inform the work of Resolution 9 in its task to "compile case studies and collect best practices regarding national uses of shared spectrum access, including DSA, and study the economic and social benefits arising from the effective sharing of spectrum resources".

With regard to TVWS availability in Botswana, there is ample unused and/or unassigned UHF spectrum which can be used to provide broadband access over shared spectrum – and thus an important opportunity to more efficiently utilize this spectrum resource towards improving many aspects of life in Botswana, including delivery of healthcare.

## 2 Objectives and target beneficiaries

The Botswana TVWS project focuses on delivering a tele-medicine health program through low-cost and long-range broadband over TVWS. The program will enable medical staff to consult with patients in remote locations, with the primary objective to increase the potential scale and reach of the health services across Botswana. Secondary goals include laying the groundwork for further low-cost Internet access that can assist in increasing renewable energy, education, healthcare, access to markets, and small business empowerment throughout Botswana.

Target beneficiaries are hospitals, clinics, and medical patients requiring the following services:

- Cervical cancer screenings;
- Dermatology screenings;
- HIV screenings and consultations;
- Tuberculosis screenings and consultations;
- Adult and pediatric care;
- Internal medicine consultations.

These beneficiaries will conduct/receive screenings and consultations by utilizing high-definition videoconferencing applications that run off 8 megapixel, high-resolution cameras at the remote clinics and hospital locations. The screenings require such high-definition imaging in order to correctly diagnose and treat prevalent medical disorders like tuberculosis. These images and video travel over TVWS-enabled broadband connections at the three remote sites and surrounding areas (within transmission distance of the TVWS signal), where they then transfer to a backhaul Internet connection that sends the video-feed directly to either medical staff at the Gaborone hub or partners at the University of Pennsylvania for diagnoses and treatment recommendations.

## 3 Geographic locations

The network is built around a central hub, three regional hospitals, and surrounding healthcare clinics, each of which is underserved by healthcare resources and broadband access. The three regional hospitals serve as TVWS base stations, which span out to include a network of seven additional clinical sites among the three locations, for a total of ten locations in Phase 1 of the project.

– Hub – Gaborone: A system hub near the University of Botswana and Princess Marina Hospital in Gaborone serves as the network hub. The central location allows the network to be connected to a high-quality wireline Internet connection that provides clear visualizations of patients in remote locations and consulting services with faculty through tele-medicine applications and devices.
– Site 1 – Lobaste: Located south-east of Gaborone, the field site at Lobaste hosts a TVWS network that provides broadband service throughout the surrounding area to clinics and potentially other sites in the future. This location will host cervical cancer screenings and dermatology screenings.
– Site 2 – Francistown: Near the northeast border with Zimbabwe, the Francistown site also connects with TVWS and offers cervical cancer screenings during the first phase of the project. In phase 2, it will move onto offering TB and HIV screenings, along with adult and paediatric care.
– Site 3 – Maun: Situated in the rural northwest of Botswana, this field site will go live in phase 2 of the project to offer cervical screenings, TB and HIV screenings, adults and paediatric consultations, along with internal medicine caregiving.

## 4 Technical architecture

The backhaul Internet connection is provided by Botswana Fibre Networks (BoFiNet – a wholesale provider of national and international telecommunication infrastructure), which provides connectivity from the Gaborone hub to the three primary sites, where TVWS base stations reside that connect to TVWS radio devices located in and around the site locations. The initial deployment will focus on ensuring clinics have the TVWS radios over which to connect, but over time will likely include other entities, like government offices and small businesses.

FIGURE A8-1

**Technical Diagram**

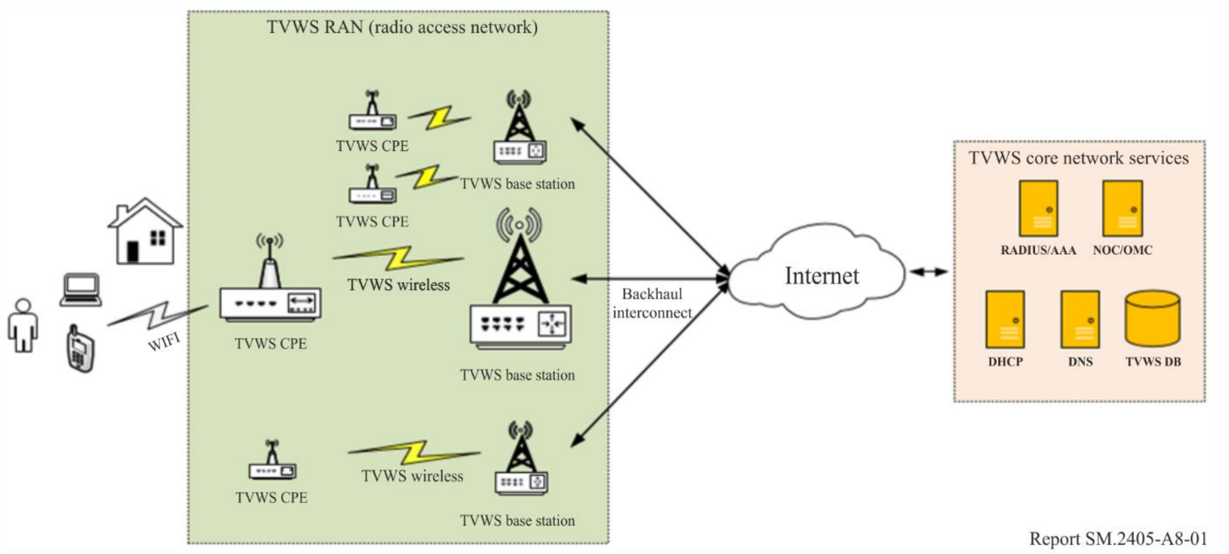



TABLE A8-1

**TV White Space radio specifications**

| Radio specifications | White Space radio |
|---|---|
| Wireless medium: | TDD OFDMA |
| Network standards: | Modified and enhanced 802.22 |
| PHY rates supported: | 12 modes from 1.5 Mbit/s to 20 Mbit/s |
| Data rate (Agg. Layer 2 UL+DL for 6 MHz) | 1 Mbit/s – 16 Mbit/s |
| Channel width: | 5.5 MHz (Americas), 7.6 MHz (Europe and Africa) |
| Operating channels: | US UHF Chan 14 – 51 (470-698 MHz), UK UHF Chan 21 – 68 (470-854 MHz) |
| Available transmit power settings: | 20 dBm (100 mW) conducted |
| Power control: | Programmable |
| Operating bands: | FCC UHF 400-1 000 MHz |
| Receiver sensitivity: | –98 dBm 3.5 dB 2.7 Mbit/s (QPSK 1/2)<br>–90 dBm 11.5 dB 7.1 Mbit/s (16 QAM 2/3)<br>–81 dBm 20.5 dB 12 Mbit/s (64 QAM 3/4) |
| Modulations | OFDM: QPSK, 16-QAM, 64-QAM |
| Antennas | PCB Bowtie Client only, integrated<br>Vertically polarized, ~0 dBi<br>DB2E UHF Panel Client or Base<br>Vertically polarized 2-elements, 6 – 9 dBi<br>Log-Periodic Base Only<br>Vertically polarized, 10 dBi |

**TVWS spectrum used in project**

– Up to six 8 MHz UHF channels used from 470-790 MHz.
– 3 UHF channels in the 470-598 MHz range.
– 3 UHF channels available in the 638-790 MHz range.

TABLE A8-2

**Channel Plan**

| UHF Ch. range | Frequency range | Total channels | Channels used | Available ch. name |
|---|---|---|---|---|
| Ch. 21-36 | 470-598 MHz | 16 | 3 | X1,X2,X3 |
| Ch. 42-60 | 638-790 MHz | 19 | 3 | Y1,Y2,Y3 |

TABLE A8-3

**Channel and Capacity Plan**

| Base station name and location | Additional site locations | Number of sectors (antennas/pies) | Concurrent users (using 1.2 Mbit/s per user) | Minimum through-put per user (Mbit/s)* | Average TCP throughput per channel (Mbit/s) | Total capacity (Mbit/s) | Minimum number of base station (BS) radios | # BS radios per sector | | | Channel allocation per base station radio | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | A | B | C | A1 | A2 | B1 | B2 | C1 | C2 |
| Athlone Hospital, LOBASTE | Tsopeng clinic | 3 | 50 | 1.2 to 10 | 10 | 60 | 6 | 2 | 2 | 2 | X1 | Y1 | X2 | Y2 | Y3 | Y3 |
| Letsholathebe II Memorial Hospital, MAUN | Moeti clinic<br>Boseja clinic<br>Maun clinic<br>Sedie clinic<br>Maun general clinic | 3 | 50 | 1.2 to 10 | 10 | 60 | 6 | 2 | 2 | 2 | X1 | Y1 | X2 | Y2 | Y3 | Y3 |
| Nyangabwe Hospital / FRANCISTOWN | Donga Clinic | 3 | 50 | 1.2 to 10 | 10 | 60 | 6 | 2 | 2 | 2 | X1 | Y1 | X2 | Y2 | Y3 | Y3 |

* Minimum throughput varies based on RF conditions (distance from site, concurrent users). 3 Mbit/s estimate for NLOS up to 10 km.

## 5 Financing

The pilot project is funded through a partnership model between BIH, Microsoft, USAID, University of Pennsylvania, and GBS. Each of the parties is making in-kind contributions of varying value:

– BIH has committed to fund $ 435 949 in network support costs.
– Microsoft has committed to fund $ 473 765 in project expenses, including software application development, the telemedicine program, a supply of Nokia phones distributed to local health personnel and centres, and Windows 8.1 desktops.
– USAID has committed to fund TV white space broadband network equipment at an estimated cost of $ 205 240.
– The University of Pennsylvania has committed to coordinate with its medical staff in Botswana to provide medical consults through the tele-medicine program co-founded by the pilot partnership.
– GBS has committed to design, build and operate the TV White Space (TVWS) network in order to deliver broadband access to the Ministry of Health Hospitals and Clinics in Botswana.
– The overall goal is for the TVWS network and accompanying healthcare delivery program to achieve financial sustainability by moving to a commercial delivery model at some future point that will not require outside grant and in-kind funding contributions.

## 6 Regulatory components

The Botswana Communications Regulatory Authority (BOCRA) granted authorization to BIH, in partnership with Microsoft, the University of Pennsylvania, and Global Broadband Solutions, to conduct a wireless broadband trial using TVWS subject to the following conditions:

– The technology is authorized on secondary basis, therefore if any interference is experienced by primary service (broadcasting) the TVWS system would be required to switch off immediately.
– Trial period for 36 months (3 years).
– The frequencies to be exploited by the authorities' entity are 470-694 MHz.
– All equipment used should be Type Approved by BOCRA.
– Trial is authorized to be conducted in the entire country servicing hospitals and clinics, as well as health posts.
– There should be 6-month periodic reporting on the progress of the project to BOCRA.
– The tariffs to be billed to interested customers should be submitted to BOCRA for approval.
– Should BOCRA develop and adopt a Framework on the operation of TVWS in general during the trial, BIH will be obliged to operate under that framework.
– The conditions may be modified (including additional conditions) by the Authority when necessary in consultation with partners.

## 7 Conclusion

Broadband applications have become an important means to improve the quality of life in underserved communities throughout the developing world. In Botswana, broadband over shared spectrum in the TVWS is helping deliver towards healthcare needs for Botswana citizens. The tele-medicine program is expected to reap economic and social benefits, and the project includes a monitoring and evaluation function to document the socio-economic impact on the communities involved.

In order to move beyond pilot projects and towards sustainable commercial deployments, BOCRA is committed to identifying and implementing ways to further promote these innovative solutions through regulatory changes that would solidify a spectrum policy framework for the use of shared spectrum. A regulatory framework will help incentivize commercial actors to consider deploying additional networks to facilitate not only remote healthcare delivery, but many other useful broadband applications throughout Botswana.

# Annex 9

# Case studies in Philippines

## 1 Introduction

This Project targets at least twenty (20) public elementary and secondary schools in Talibon, Ubay and Tubigon (10-km radius) and nearby adjacent barangays at the Bohol seashore to serve broadband connectivity requirement of ECOFISH (Ecosystems Improved for Sustainable Fisheries) in its objective to make the fisheries sector sustainable through the effective management.

DOST-ICTO is targeting the deployment of Base Station at ICTO-TELOF’s existing radio transmission towers and CPEs at Public Elementary and High Schools as part of the non-commercial TVWS pilot projects. Broadband connectivity in the municipalities of Talibon, Tubigon and Ubay in Bohol are either served by ICTO-TELOF or private sector. However, the majority of the barangays and schools, particularly those in the remote areas and nearby islands are still not yet connected to the internet due to lack of last mile infrastructure. Broadband Wireless Access deployment thru TVWS technology is foreseen suitable solving last mile connectivity gaps in these areas.

## 2 Strategies

The project aims to expand the broadband connectivity coverage to still unserved and underserved barangays and schools in Talibon, Tubigon and Ubay Local Exchanges of ICTO-TELOF in Bohol area. It aims to serve the public elementary and secondary schools in Talibon, Tubigon and Ubay (10-km radius) as well as adjacent barangays in said municipalities. It is also expected to serve broadband connectivity requirement of ECOFISH thru free public Wi-Fi in its objective to make the fisheries sector sustainable through the effective management. In addition to attaining broadband connectivity for various government services in public schools, hospitals, and Community e-Centres (CeCs) this pilot project as part of the DOST-ICTO’s plan, when executed also aims to 1) providing the data necessary to develop and finalize the policies, rules and regulations to institutionalize the adoption of TVWS technologies consistent with national goals, 2) aiding the TVWS Technology Partners in refining their products and services for the specifics of the Philippine environment, and 3) aiding the TVWS Database and Connectivity Service Providers with essential data and experience to develop their services prior to the envisioned nationwide rollout.

On the status of the said project, the length of the deployment of the TV White Space project is expected to be competed from one year until two years. The ICT Office had deployed the TV White Space technology in Bohol purposely because of the Earthquake that struck this province where communication was totally cut-off making the people in the area isolated from the outside world. Thus, relief and rehabilitation efforts of private and government agencies were hampered because of the absence of communication. The TV White Space was deployed at the plaza, municipal building and at the government centre purposely to provide free wi-fi to the people in the community to be able to make a call and communicate with their relatives using the social media such as Viber, Line, Skype, etc. At the same time, the TV White Space technology was utilized in Tacloban which was heavily hit and damaged by Typhoon Haiyan (Yolanda). ICT Office deployed TV White Space in the area to far extend the VSAT from the DOST Regional Office to Philippine Science High School (Pisay), Leyte and to Los Bumbero, a Spanish Volunteer, where the evacuation centres are present. In addition, TV White Space was used to extend the internet signal from the Smart Tower in Tanauan, Leyte to the municipal hall building and the Community e-Centre purposely for the public to use and to communicate via email and chat with their relatives abroad and locally. We put up e-Health in the government centre using RX Box that is passing thru the TV White Space.

The TV White Space Bohol Pilot Project deployment covers the following area: the installed TVWS Talibon Base Station provide connectivity within 10 km. radius to five elementary/secondary public schools and Free Wi-fi to BFAR-USAID ECOFISH members, nearby Rural Health Units (RHU), Barangay Halls and to the public; the installed TVWS Tubigon Base Station provide internet to an elementary, Free Wi-Fi to public plaza, public market and church as well as broadband connectivity to a community hospital and different government agencies nearby; and the installed TVWS Ubay Base Station, expected beneficiaries of twelve elementary public school, a community e-centre and Connectivity with BFAR-USAID ECOFISH Project, RHUs and Barangay hall adjacent to the schools plus free public Wi-Fi to the public.

| **TV WHITE SPACE PROJECT DEPLOYMENT IN BOHOL** | |
|---|---|
| Tubigon Base Station: | Installed two (2) master/channel Base Station with an aggregate capacity of 24 Mbit/s (~12 Mbit/s per channel).<br>Installed three CPEs in the following locations:<br>Tubigon Community Hospital serving connectivity to different government agencies inside Tubigon Government Center (these are PNP, DSWD, DOST, MCTC, TESDA as well as the Tubigon Rural Health Units (RHU);<br>Tubigon Multi-purpose Gym with Public Wi-Fi access to cover Tubigon public market, public plaza and Tubigon church;<br>Tubigon Central Elementary school with Wi-fi Access point. |
| Ubay Base Station: | Installed four (4) master/channel Base Station with an aggregate capacity of 48 Mbit/s (~12 Mbit/s per channel).<br>Installed thirteen (13) CPEs in the following public elementary schools and CeC:<br>Poblacion<br>Casate<br>Tapon<br>Achila<br>Camambugan<br>Bood<br>Katarungan<br>Carlos P. Garcia CeC (C.P. Garcia)<br>Tipolo |

| TV WHITE SPACE PROJECT DEPLOYMENT IN BOHOL | |
|---|---|
| | Kalanggaman<br>San Isidro<br>Tapal<br>Sentinela<br>Emelda |
| Talibon Base Station: | Installed three (3) master/channel Base Station with an aggregate capacity of 48 Mbit/s (~12 Mbit/s per channel).<br>Installed five (5) CPEs in the following sites:<br>San Jose National High School<br>San Pedro Elementary School, Talibon<br>Sto. Nino Elementary School, Talibon<br>Ginubatan Elementary School, Trinidad<br>Pinamgo Barangay Hall, Buen Unido |

On the partnership and financing, the DOST-ICTO instituted a partnership with various government agencies, technology providers and stakeholders thru Memorandum of Agreement, namely, National Telecommunications Commission (NTC), Department of Education (DepEd), Microsoft, Nityo InfoTech, Federation of International Cable TV and Telecommunications Association of the Philippines (FICTAP), ABS-CBN, ECOFISH, BFAR and USAID.

With regard to the applications and services provided, the government launched a TV White Space based network to provide an immediate on-the-ground communications network for disaster relief respondents and victims of Typhoon Haiyan. It was established in a matter of hours after the disaster struck, it provided a network immediately for two-way voice and data wireless communications for anyone with functioning devices such as handsets, laptops, tablets, etc. and cost less than a tenth of the price alternative solutions. This TVWS project connects fishing communities to broadband allowing local government to access a national registration system directly, enabling municipalities to immediately distribute critical identification documents, certificates and licenses to the fishermen that need them, while also providing the national police and other agencies immediate access and connection to a central database to monitor compliance.

The TVWS Project was intended as Rural Broadband Deployment for Public Utilization such as 1) ICT for Public Education used as multimedia instruction, access to the better teachers and information access and delivery; 2) Telehealth for Rural Health Units used in primary healthcare delivery, access to specialists and health management, health care access for all; 3) Governance used in LGU/NGA coordination and access toe-Government services and great public engagement; 4) Disaster Mitigation and Response used in data collection via sensor network and information (early warning) delivery; 5) Commerce and Industry used in e-Business – marketing, selling, distribution, support, etc. and productivity enhancement, access to knowhow. Below is the TVWS technical specifications of the system.

| TVWS technical specifications | |
|---|---|
| **System specifications** | |
| Frequency bands | 630-750 MHz |
| Max PldB @ 1.5 Mbit/s | +31 dBm |
| Channel bandwidth | 20 / 10 / 5 MHz |
| Receiver sensitivity | –99 dBm |

| TVWS technical specifications | |
|---|---|
| **System specifications** | |
| Data rates | 1.5 to 13.5 Mbit/s |
| Modulation | QPSK & 16-QAM |
| Range | Up to 10.7 km |
| RF interface | MMCX |
| Backend interface | 32-bit miniPCI |
| Power rating | 1.6A @ 3.3V DC |
| Form factor | 3.3” × 2.3” × 0.5” |
| Operating temperature | −33 to +55 C |
| Operating humidity | Up to 95% non-condensing |

For the installation and deployment, CPEs were installed in coordination with the school officials connecting to base stations providing internet. Since there is no regulation, the deployment is more on public or for government use especially on public schools that do not have internet because the students badly needed this internet to be well-informed on what is happening, but the problem is that there is no last mile in schools that is why they cannot use internet. Thru the use of TV White Space technology, the schools were provided with internet and at the same time, even other barangays, since our topology area are split, using fibre optics is not cost effective except with the use of radios with a distance from about 7 to 10 km apart using TV White Space and other line-of-sight and even beyond the sea/ocean point to multi point of TVWS to cover line of site and outside the signal traveling over water (Figs A9-1 to A9-4 in the Attachment to this Annex 9).

## 3 Challenges

The challenges encountered during the implementation of the project are the initial resistance from teachers because they are not aware of the benefits of the internet. At the same time, the people in the area/community are uncertain, especially the old people because they do not know the benefits of the internet. This project benefited the store that is surrounding the area because it has become a gathering area for people who want to use the internet and also becomes a social area in the community.

## 4 Outcomes

The benefits realized is the project is that the schools were provided with free internet, fisher folks were able to register at the same they can coordinate using VoIP like fibre, Skype, etc. at the same time the population surrounding the schools can be able to use internet after the school is not using it or it is open after school hours and the surrounding of the school becomes social area. Those who want to use internet are going there to be able to use the internet.

Best practices discovered on this project is sharing the internet of the schools to the community especially after school hours instead of the bandwidth is wasted while no one is using. It is our best practice to share the internet when the school is not using the bandwidth, we open it up to the public as a free Wi-Fi. At the same time, the best practice during calamity since there is free Wi-Fi, those affected people or the victims who could not afford costly long distance or could not make a call due non-availability of long distance who are in the evacuation centre including the volunteers are able to communicate with their loved ones using VoIP like fibre at no cost for them. They are able to give help, able to ask for assistance or help to their relatives here and abroad. At the same time, they are able to give their situation to their relatives and because of this their relatives are at peace upon knowing their situation.

## 5 Conclusion

The TV White Space Pilot Project deployed in Talibon, Tubigon and Ubay, Bohol has been beneficial specifically to DepEd which is the recipient of the project. It provides free Wi-Fi to students as well as to teachers in the schools both Elementary and High School students. Not only the students and teachers benefited from this project but also the people in the community surrounding the schools because after school hours, the free Wi-Fi can be accessed and used by them. This free Wi-Fi was also installed in Municipal Plaza, Community Hospitals, Rural Health Units, Multi-Purpose Gym that covers public market, public plaza and the church.

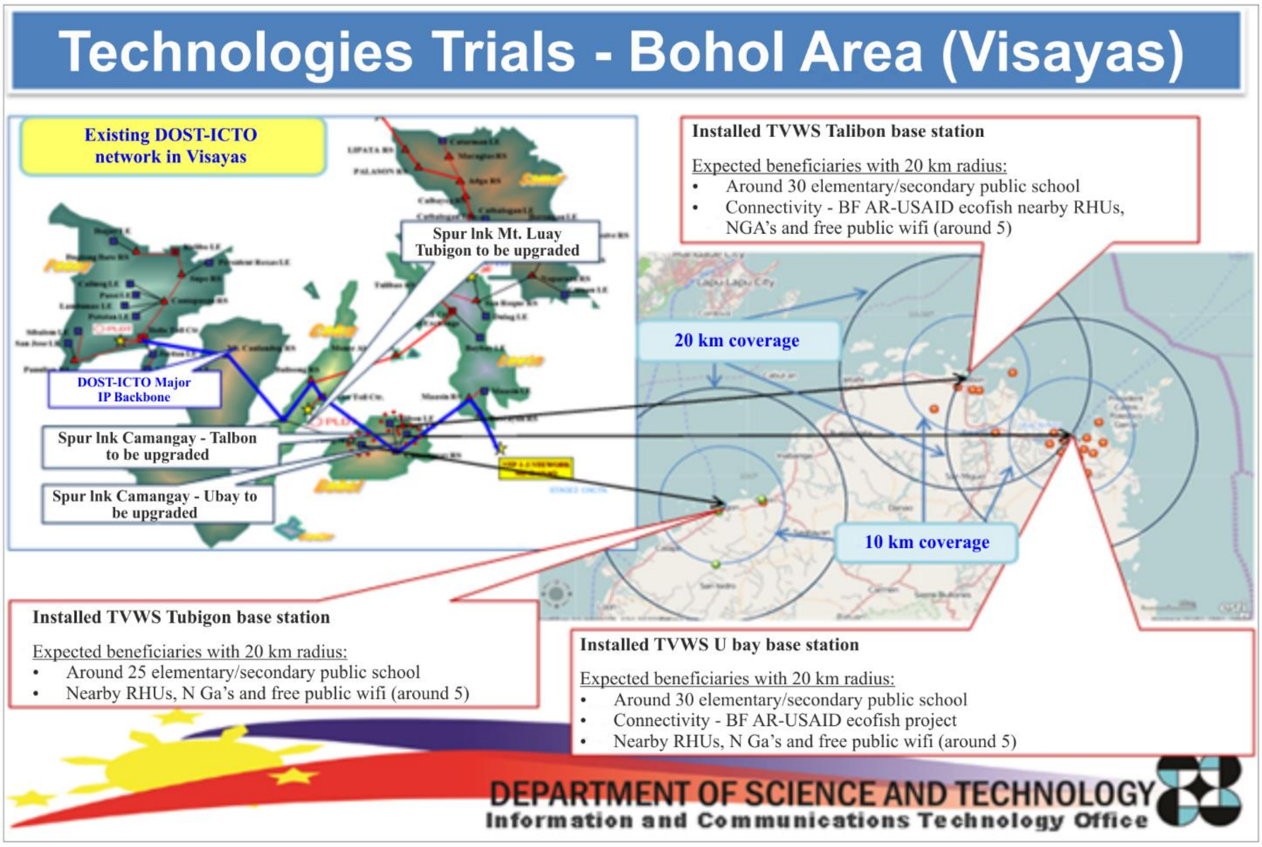
At the same time, the TV White Space technology was also deployed and utilized in Bohol purposely because of the earthquake that struck this province where communications was totally cut-off leaving the people in the area isolated from the outside world and the relief effort of the government agencies were hampered due to absence of communication. It was also utilized in Tacloban City which was heavily hit and damaged by Typhoon Haiyan to provide an immediate on-the-ground communications network for disaster relief respondents and victims of the super typhoon order for the people to communicate with their relatives locally and abroad and to the volunteers that are present at the evacuation centres.

With the TV White Space technology deployed in Talibon, Tubigon and Ubay, Bohol, rural communities in the area both the schools and barangays have now access to broadband enabled services that would contribute economic development in the said areas.

# Attachment
# to Annex 9

FIGURE A9-1

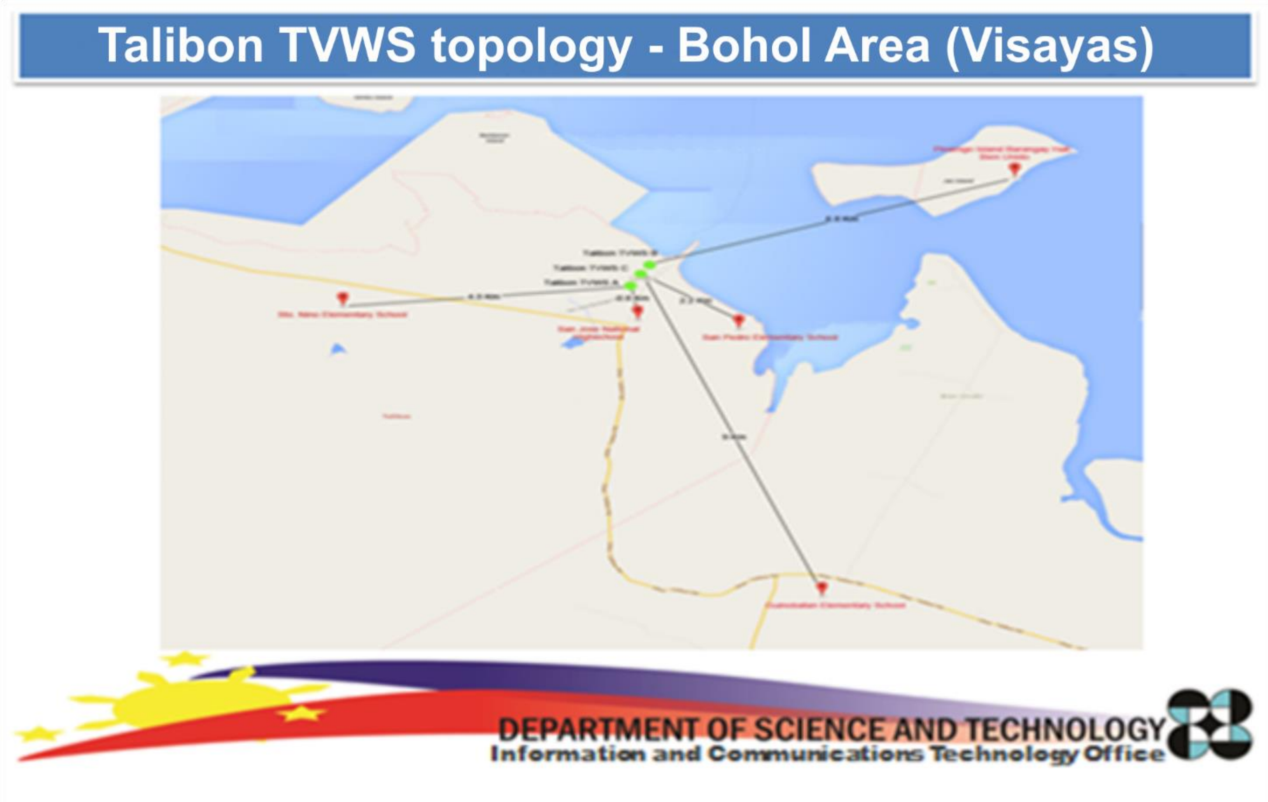
**Talibon, Tubigon and Ubay TV White Space Area Coverage**




Report SM.2405-A9-01

FIGURE A9-2

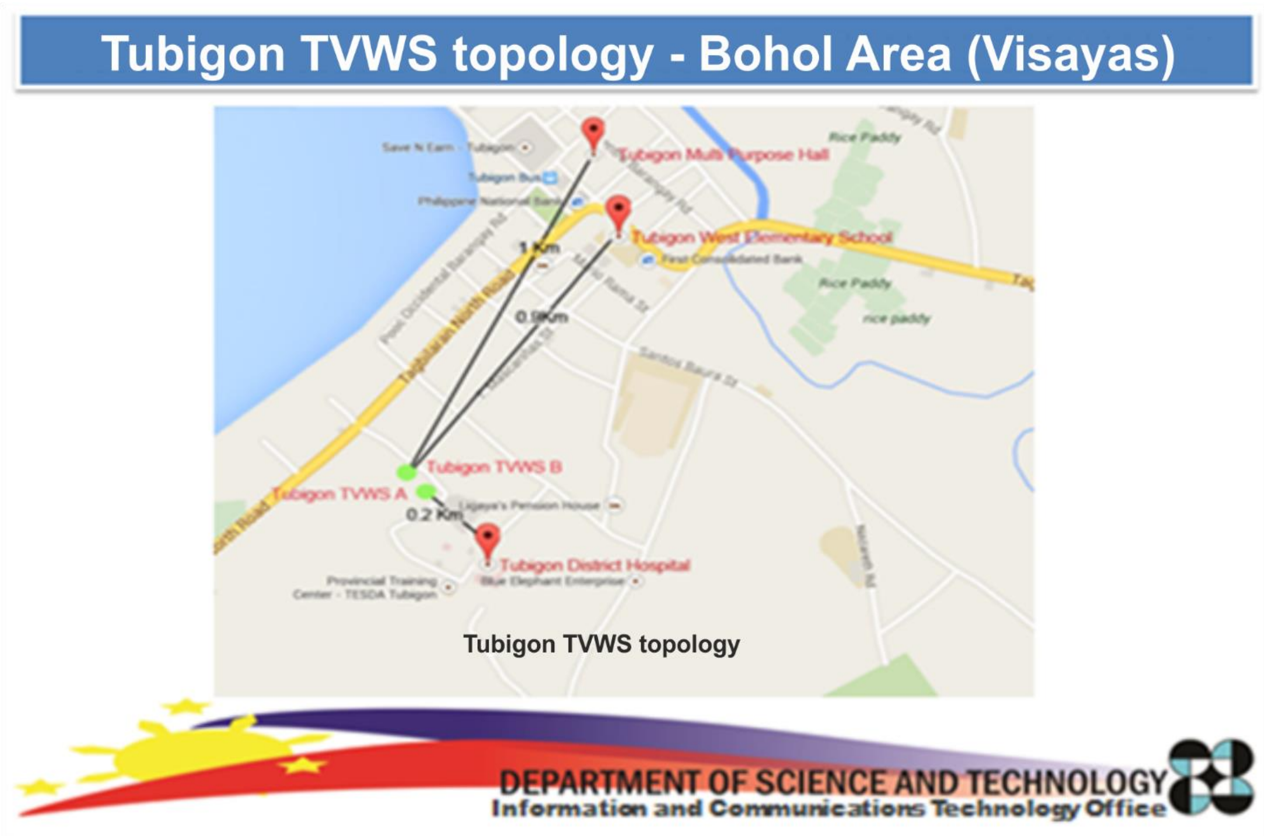
**TVWS Project Coverage in Municipality of Talibon**




Report SM.2405-A9-02

FIGURE A9-3

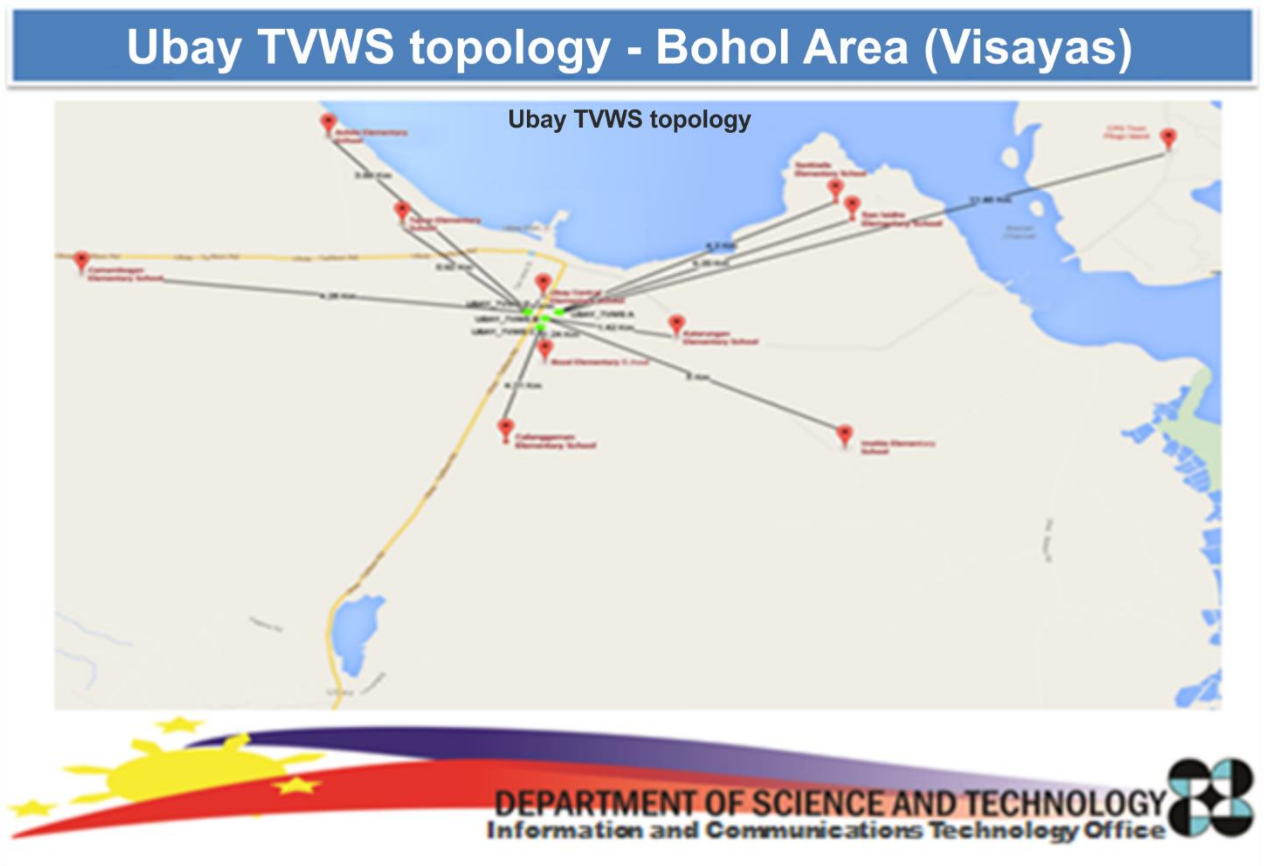
**TVWS Project Coverage in Tubigon Municipality**




Report SM.2405-A9-03

FIGURE A9-4

**TVWS Project Coverage in Ubay Municipality**




Report SM.2405-A9-04

# Annex 10

## Case studies in Korea (Republic of)

### 1 Introduction

In recent years, a paradigm shift in spectrum management has been taking place via broadcasting and communications convergence media with the proliferation of converged applications. As spectrum resources are a valuable and an intangible asset of countries and the value of frequency resources has further increased with the development of various wireless communications technologies, many countries are now actively promoting the development of new wireless technologies and the introduction of policies that can help increase the efficiency of spectrum utilization. However, it is a great challenge to continue to supply new frequency bands in response to the advent of new technologies by relocating the existing spectrum bands and therefore, countries around the world need to focus on spectrum sharing.

The Republic of Korea decided to introduce TVWS in the band 470-698 MHz within TV broadcasting frequency bands. In order to achieve the maximum efficiency for the use of frequency resources, Korea introduced TVWS commercial services in the band 470-698 MHz.

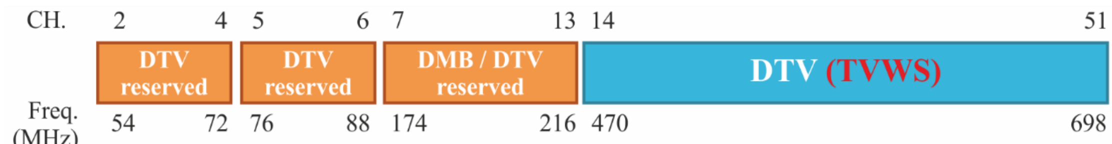
## 2 Recent regulatory actions

In 2010, Korea announced TVWS plan for the introduction of Wi-Fi services in rural area and information delivery at museum or at stadiums.

In 2011, a plan was announced to utilize TV White Space in frequency band of 470-698 MHz. The TVWS applications include such as 1) wireless internet for rural areas; 2) information delivery for museums, stadiums and other small areas; 3) disaster prevention and management, such as video transmission used in underground for rescue and safety activities; and 4) environmental information delivery on water and power usage. Figure A10-1 shows the TVWS Spectrum Band in Korea.

FIGURE A10-1

**TVWS spectrum band**




Report SM.2405-A10-01

Korea also developed the Information Strategy Planning (ISP) and established the unlicensed based TVWS technical requirements to build a TVWS Data Base (DB), while protecting the 470-698 MHz frequency band, including terrestrial DTV and licensed wireless microphone.

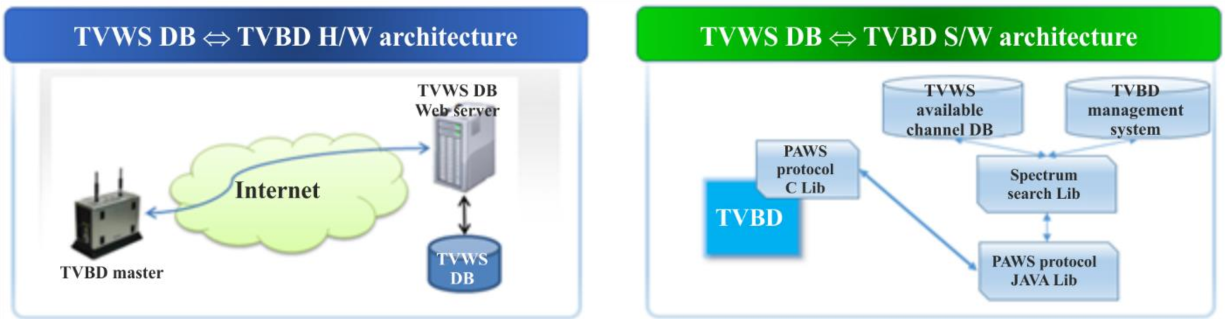
In 2013, the TVWS DB was set up in order to provide location-based TVWS channel availability lists to TVBD (TVWS Band Devices) with in-built GPS receiver. The TVWS Geo-location DB access method allows TVBD to access to the DB, transmit the current location information, and receive the list of available channels of the current location from the DB. The available channels of TVWS in Korea can be found in the "TVWS Available Channel Search System (https://www.tvws.kr)".

In 2016, Korea government made a new public notice to allow usage of the TVWS and on non-license basis.

In April 2017, the first TVBD product that meets the regulation was released, and Korea began to provide TVWS commercial service.

FIGURE A10-2

**TVWS DB systems**




Report SM.2405-A10-02

Separation distances to protect for digital television reception and wireless microphones were applied to the algorithm of TVWS DB, which takes account of TVBD type, transmit power, and antenna height. Figure A10-2 shows the TVWS DB systems.

Two kinds of TVBDs, fixed and portable are taken into account to be operated on available channels in frequency band from 470 MHz to 698 MHz (TV channels 14 to 51). The technical requirements for the TVBD are shown in Table A10-1.

TABLE A10-1

**The technical requirements of TVDB**

| **TVBD type** | **Fixed** | **Portable** | |
|---|---|---|---|
| Operation mode | Co-channel/adjacent channel with separation distance | Co-channel/adjacent with separation distance | Adjacent channel without separation |
| Maximum power spectral density supplied to antenna | 1 W / 6 MHz<br>12.2 dBm / 100 kHz | 100 mW / 6 MHz<br>2.2 dBm / 100 kHz | 40 mW / 6 MHz<br>–1.8 dBm / 100 kHz |
| Antenna gain | 6 dBi | 0 dBi | 0 dBi |

## 3 TVWS Pilot Projects

In 2011, Korea conducted a survey to collect demands for TVWS and its feedback with regard to the feasibility of TVWS applications from a total of 200 organizations, including local governments, public institutions, broadcasters and telecommunications operators. The result of opinions received shows that the most suitable application of TVWS applications is Wi-Fi (46%), followed by disaster and emergency information delivery (22%), traffic information and security (13%) and Smart grid (5%).

In the same year, TVWS experimental services were carried out to find the suitable service models for Jeju and inland areas. As a result, a Wi-Fi network in Jeju, underground disaster and emergency video transmission in Namyangju were introduced as TVWS applications.

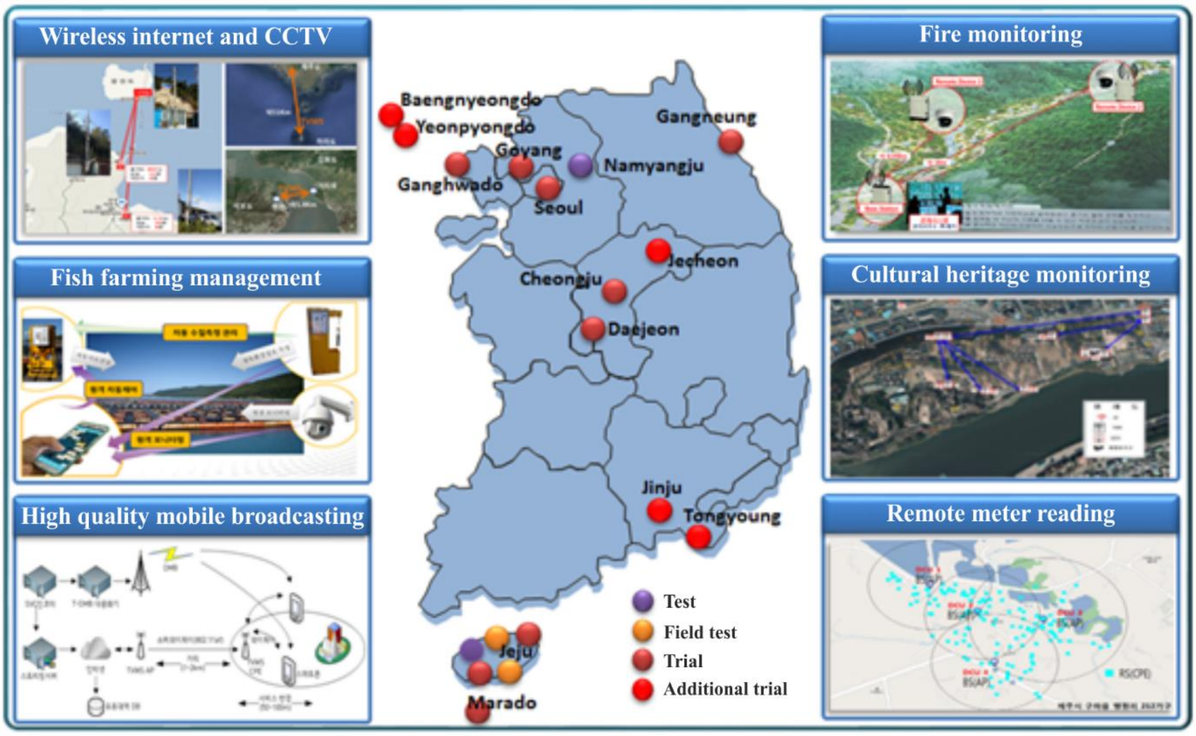
In 2013, Korea government selected five consortiums to expand the nation’s TVWS pilot projects. They are as follows:

1) High-definition hybrid-DMB service in Goyang;
2) Island wireless internet service and tourist information in Jeju;
3) Telescreen, fire monitoring and other disaster and safety in Gangneung, Seoul, Cheongju, Daejeon and Ganghwado;
4) One-member households safety check using power meters and meter data analysis, especially, for the elderly and the disabled in Jeju;
5) Content Delivery Network (CDN) for smart advertising in Daejeon.

Figure A10-3 describes the TVWS Pilot Projects.

FIGURE A10-3

**TVWS Pilot Projects**




Report SM.2405-A10-03

Korean manufacturer succeeded in developing more updated TVBD than existing devices in 2014.

In 2015 and 2016, local government conducted additional TVWS pilot services, which includes wireless internet and CCTV service in remote areas such as Jechon and Backnyeongdo, aquaculture big-data provision for fish farm management in Tongyoung, and fire detection system for cultural heritage in Jinju.

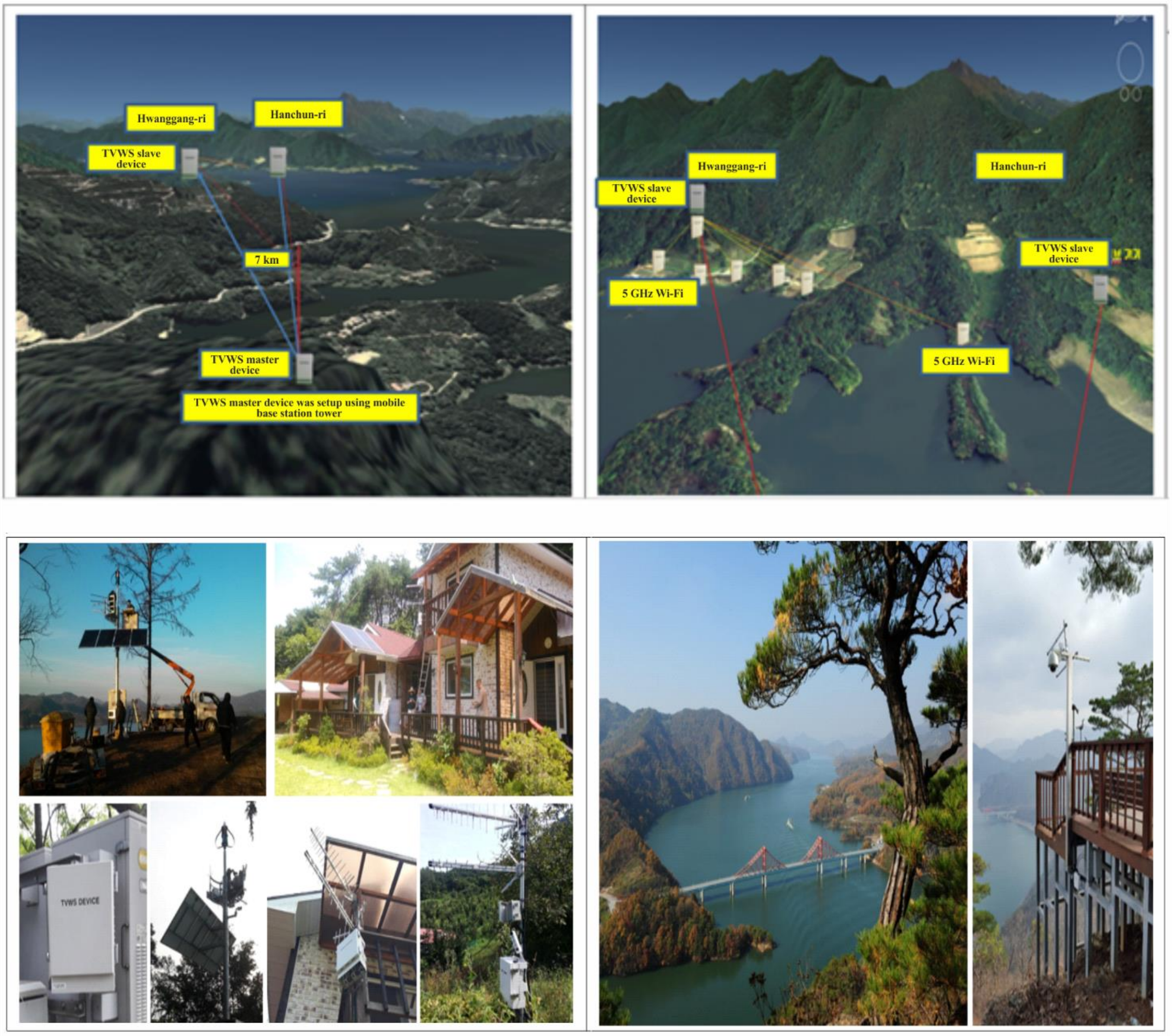
Among them, there was an isolated place in Jecheon which area was submerged by the construction of a dam and an artificial lake in 1985. Communication networks and electrical equipment were unavailable to reach the area due to its isolation. A solar power generation and TVBD made the usage of the wireless internet available.

Favourably, it did not cost much to construct TVBD networks. In comparison to M/W, the cost is 76% cheaper and 95% cheaper than submarine communications cable.

The TVWS backhaul for wireless internet service at remote area in Jecheon is shown in Fig. A10-4. The TVBD's specifications and throughput used for pilot are summarized in Tables A10-2 and A10-3, respectively.

FIGURE A10-4

**TVWS Backhaul for wireless internet service at remote areas in Jecheon**




Report SM.2405-A10-04

TABLE A10-2

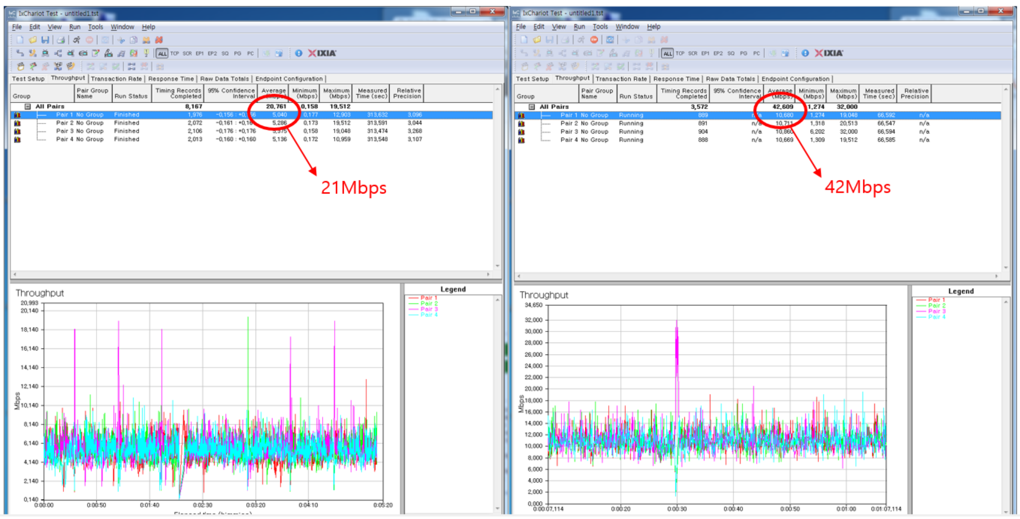
**TVBD specifications**

| Category | Specification |
|---|---|
| Frequency Range | 470 ~ 698 MHz |
| Tx Power | 27dBm/6MHz, 30dBm/12MHz |
| TX Power Control Step | 1dB |
| TX EIRP | 36dBm/6MHz, 39dBm/12MHz |
| TX Spectrum Mask | 55dBr |
| Max RX Level | -40dBm/carrier |
| MIMO | 2×2 (Vertical/Horizontal) |
| Carrier Bandwidth | 6MHz or 12MHz(adjacent) |
| Multiple Access | CSMA/CA |
| Modulation | QPSK, 16QAM, 64QAM |
| Service Distance | Over 7Km @ LOS |
| Maximum Throughput | 21Mbps(6MHz), 42Mbps(12MHz) |
| WAN/LAN Interface | RJ-45 |
| AC Power | 220V |
| Size | 310mm × 440mm × 140mm |

TABLE A10-3

**TVBD Throughput**

☐ **6MHz(1CH) BW Throughput** ☐ **12MHz(2CH) BW Throughput**




Available TVWS channels can vary by region. For instance, in case of Fixed TVBD, has an average of three available channels are founded in metropolitan areas and an average of seven available TVWS channels in provinces of Korea. TVWS Pilot Project of Jecheon has demonstrated the 21 Mbit/s throughput only via one TVWS channel (6 MHz bandwidth) at a distance of 7 km away from radio station connected to public access, and a 42 Mbit/s throughput using two bonding adjacent channels (12 MHz bandwidth). Therefore, the residents are able to access to Internet services and Internet commerce.

## 4 Conclusion

Korea believes that TVWS will help to solve the digital divide problem and make wireless broadband access more affordable across the country. It also implies that spectrum sharing could alleviate the scarcity of frequency resources and increase public convenience in the coming hyper-connected society.

# Annex 11

# Case studies in Colombia (Republic of)

## 1 Introduction

The frequency band 470–698 MHz is allocated to the TV broadcasting service in Colombia. However, this frequency band is not fully utilized by TV transmissions in rural areas, creating an opportunity to provide additional radio applications, thus promoting the efficient use of the radio spectrum.

Because of this, authorizing TVWS in Colombia has been a solution to improve the spectrum utilization as well as to provide last-mile internet access in rural areas, where the highest number of unconnected people live. In other words, TVWS in Colombia aim to close the gap between the optical fiber end-points located in all the small towns and the unconnected rural surrounding areas.

However, setting forth the Colombian TVWS regulatory framework is required to overcome some challenges described below.

## 2 TVWS interference measurement

TV broadcasting in Colombia is currently transmitted using 6 MHz NTSC-M standard for analogue TV as well 6 MHz DVB-T2 standards for digital TV. Considering that no interference measurements had been made for a 6 MHz DVB-T2 signal interfered by a TVWS signal, it was required to measure the corresponding protection ratios in order to determine the technical conditions under which no interference is caused to digital TV reception.

Analogue TV protection ratios were also measured with the aim to compare and validate the results with the protection ratios used by United States of America's Federal Communication Commission [12], given that the USA used the same analogue TV standard as Colombia.

The required measurements were performed following the guidelines found in [13], [14] and [15]. Eight digital TV receivers and six analogue TV receivers were subject to those measurements. Also, to reduce the amount of measurements, only four DVB-T2 modes were employed, corresponding to the three modes currently used in Colombia and the mode most sensitive to interference. The measured protection ratios are shown below:

TABLE A11-1

**Measured TVWS to TV protection ratios**

| Channel | Analogue TV protection ratios (dB) | Digital TV 16-QAM 1/2 protection ratios (dB) | Digital TV 64-QAM 2/3 protection ratios (dB) | Digital TV 64-QAM 3/4 protection ratios (dB) | Digital TV 256-QAM 5/6 protection ratios (dB) |
|---|---|---|---|---|---|
| N | 39.5 | 10.1 | 15.4 | 17.4 | 25 |
| N±1 | −18.4 | −39.6 | −39.6 | −32 | −23.5 |
| N±2 | −18.3 | −51 | −44.7 | −43.3 | −34.3 |
| N±3 | −22.1 | −55.3 | −47.7 | −46.6 | −37.7 |

It is worth noting the similarity between N±1, N±2 and N±3 analogue TV protection ratios. Also, the difference between N±1 and N±2 digital TV protection ratios is 10 dB approximately, while the difference between N±2 and N±3 digital TV protection ratios is 3 dB approximately. Because of this, it is important to consider upper adjacent channels in the available channels calculation performed by the geolocation database.

## 3 Field testing

TVWS field tests were made to study the technology performance and social impact. Three rural public primary schools were selected as the end users. The deployment in those schools were made through a public-private partnership composed by:

1) **Agencia Nacional del Espectro** (National Spectrum Agency): Public organization in charge of the radio spectrum management. This institution was the leader of the partnership. It led the technical aspects of the field tests.

2) **Autoridad Nacional de Televisión** (National Television Authority): Public institution responsible for all regulatory aspects of the TV service, including TV broadcasting frequency assignment. Its participation included inspecting the tests and issuing the authorization for using the available TV broadcasting frequencies.

3) **Ministerio de Educación Nacional** (National Education Ministry): Public entity in charge of formulating the national policy for a quality and competitive education. This Ministry supplied a list of candidate unconnected rural primary schools that satisfied certain criteria. Also, it helped assessing the social benefit of the tests.

4) **Ministerio de Tecnologías de la Información y las Comunicaciones** (ICT Ministry): Ministry responsible for establishing the national ICT policy. Its participation in the test included assessing the performance of the technology for future social projects and obtaining a list of Internet service providers and available Internet access locations for the field tests.

5) **Computadores para Educar** (Computers for Education): Public-Private organization with the mission of delivering computers to public schools nationwide to promote ICT access for education. This organization gave a list of the public schools owning at least one computer (many public schools lack computers). Moreover, it gave ICT appropriation lectures to the teachers of the selected schools.

6) **Colombian Army**: The Army contributed in various aspects in the field testing such as going to every candidate school to obtain its geographical coordinate and offering safety in the installation of the TV White Space devices.

7) **Microsoft**: This private corporation donated the tested devices, paid for its installation and offered overall technical advice.

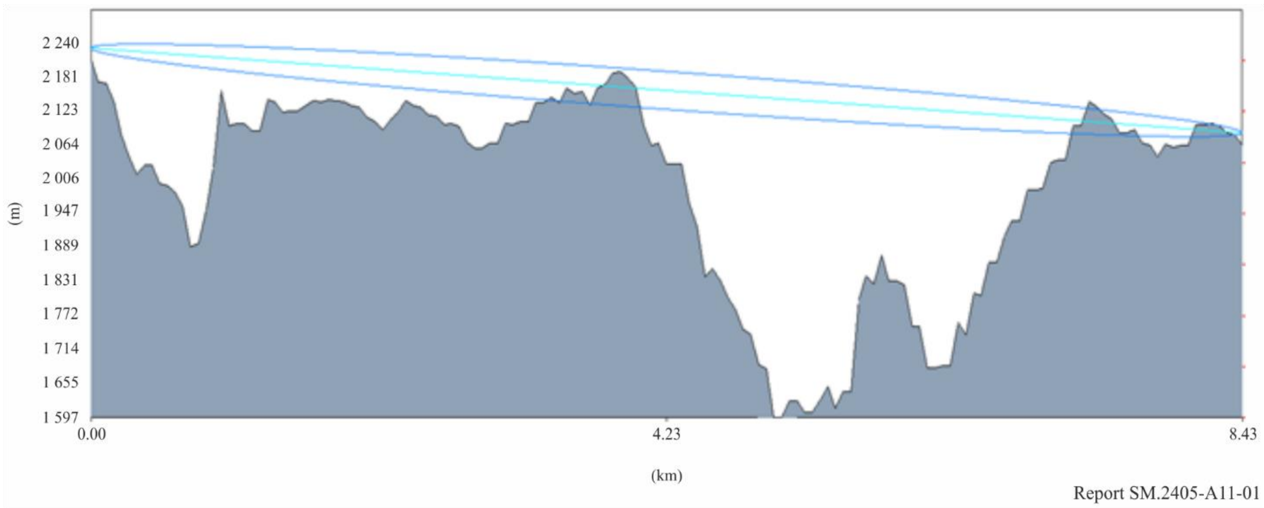
8) **Azteca Comunicaciones**: This private company is the principal optical fibre network operator in Colombia. It was contacted by the ICT Ministry to provide Internet access for the field tests. They also helped in the device installation and maintenance.

The field tests results showed the rapid appropriation of ICT services in the schools and communities. Although the field tests were completed after three months, these schools kept receiving the wireless Internet service for a year. During this time, the schoolteachers gave lectures to their students and the community about the use of computers, Internet, and ICT services. The students used the Internet service in their classes in the morning while the local community did so in the afternoon for recreational purposes. The offline educational content the schools had in their computers and tablets were complemented by online content created by the National Education Ministry, greatly improving the resources available for lectures.

Additionally, NLoS performance was satisfactory, confirming that the use of lower frequency bands is preferred for last-mile connection in the Colombian rough terrain. Figure A11-1 shows one of the terrain profiles with multiple LoS obstructions in which communication was successfully established.

FIGURE A11-1

**Terrain profile of successful link with multiple LoS obstructions**




## 4 TVWS regulation

TVWS regulation in Colombia is included in the licence-exempt regime. This implies that a TVWS device should cease operation if interference is caused to TV reception. Also, current and future TV broadcasting stations as well as new frequency allocations have priority over any TVWS device.

In addition, Colombia TVWS regulation also set the maximum transmission power and unwanted emissions in such a way that that devices manufactured abroad are compatible, thus exploiting economies of scale. Maximum antenna gain was selected to allow most UHF antennas types, such as panel, Yagi, and log-periodic ones.

Furthermore, because TVWS's purpose in Colombia is to connect rural isolated areas, only fixed devices, which allow long connection distances, are authorised.

Moreover, because the CPE could be located up to 20 km away from the BS, CPE and BS channel availability could be different. Therefore, automatic geolocation capability is required for both the

BS and the CPE. However, we are reviewing this restriction considering that currently available CPE devices do not support it.

Finally, devices requesting the database for an available channel list must report back the chosen channel. This provides useful information to detect and solve interference.

## 5 TVWS deployments

By April 2018, several TVWS deployments have been made in Colombia by public organizations as well as private companies with the aim to assess the device performance in comparison with alternative technologies. Most of these deployments are oriented towards the education and agricultural sectors.

Considering that the Colombian TVWS database was not implemented by the time of these deployments, the channel availability was directly informed by the administration to the deployment operators and the devices were manually configured to transmit in the available channels. These deployments should be adjusted to be able to receive the channel availability from the database when it is operative.

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