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Soares, Thiago Aguiar; Cardoso, Paulo E. R ; Dias, Ugo Silva; 2022. Spectrum Availability for the Deployment of TV 3.0. SET INTERNATIONAL JOURNAL OF BROADCAST ENGINEERING. ISSN Print: 2446-9246 ISSN Online: 2446-9432. doi: 10.18580/setijbe.2022.2. Web Link: http://dx.doi.org/10.18580/setijbe.2022.2

Spectrum Availability for the Deployment of TV 3.0

Thiago Aguiar Soares, Paulo E. R Cardoso, Ugo Silva Dias

***Abstract*—In this paper, we study the current and future spectrum availability of the VHF and UHF bands in Brazil for the deployment Next-Generation Digital Terrestrial Television Systems, which are being studied under the "TV 3.0 Project" initiative, coordinated by The Brazilian Digital Terrestrial Television System Forum (SBTVD Forum). Coverage simulations of all expected operating television stations were computed in different scenarios to estimate the spectrum usage over the Brazilian territory. Results indicate that even after the analog TV switch-off there will be no spectrum availability in the main metropolitan regions for simulcast transmissions between the current ISDB-Tb System and the future TV 3.0. Hence, hybrid approaches should be implemented to smoothly introduce a new digital television system in Brazil.**

***Index Terms*—Digital Terrestrial Television (DTT), Next-Generation Digital Terrestrial Television Systems, Regulation, Spectrum Policies, TV 3.0.**

I. Introduction

Digital terrestrial television (DTT) plays an important role worldwide in providing free-to-air audiovisual content with better picture and sound quality. DTT is being introduced in the VHF/UHF bands by administrations from 1997. The first-generation DTT systems were standardized by International Telecommunications Union (ITU) in Recommendation ITU-R BT.1306 - Error correction, data framing, modulation, and emission methods for digital terrestrial television broadcasting [1]. Four systems are currently standardized in the above-mentioned recommendation:

- ATSC - Advanced Television Systems Committee;
- DVB-T - Digital Video Broadcasting - Terrestrial;
- ISDB-Tb - Integrated Services Digital Broadcasting - Terrestrial;
- DTMB - Digital Television Terrestrial Multimedia Broadcasting

Since their standardization, DTT Systems have been widely implemented worldwide and several countries have started switching-off analog TV services. In many countries, this process has still been completed, mainly in developed countries in North America, Europe, and Asia [2].

Driven by the rapid improvement of TV sets definition and the necessity of higher quality and connectivity, DTT systems continue their technological evolution. In November 2010, ITU started to standardize second-generation systems with the approval of Recommendation BT.1877: Error-correction, data framing, modulation, and emission methods and selection guidance for second-generation digital terrestrial television broadcasting systems [3]. In its recent version there are three standardized systems:

- ASTC 3.0 - Advanced Television Systems Committee 3.0;
- DVB-T2 - Digital Video Broadcasting - Terrestrial 2;
- DTMB-A - Digital Television Terrestrial Multimedia Broadcasting

These recommended systems have already been implemented around the world and new systems are also being developed for future operation. Advanced Integrated Services Digital Broadcasting - Terrestrial, an evolution of ISDB-Tb System [4] and 5G Broadcasting, based on a set of 3GPP specifications [5], are well-known candidates for the next standardized Second Generation DTT Systems.

The second generation of digital terrestrial television broadcasting transmission systems is meant as systems offering higher bit rate capacity per Hz and better power efficiency in comparison to the systems described in Recommendation ITU-R BT.1306 and there is no general requirement for backward compatibility with first-generation systems [3]. So, transitioning from first to second-generation DTT systems will require spectrum availability.

In Brazil, studies for Next-Generation Digital TV Systems have already been initiated. In July 2020, The Brazilian Digital Terrestrial Television System Forum (SBTVD Forum) released a Call for Proposals (CfP) seeking input from interested organizations for Brazil's next-generation Digital Television system components and sub-components [6] . The initiative is called "TV 3.0 Project". The CfP received in total, considering its 6 system components (Over-the-air Physical Layer, Transport Layer, Video Coding, Audio Coding, Captions, and Application Coding), 36 responses from 21 different organizations worldwide [1].

The TV 3.0 Project Phase 2 "Testing and Evaluation of the candidate technologies" was carried out from July 2021 to December 2021. Considering the test results, as well as the market and intellectual property aspects of the candidate technologies, some components have already been defined[1]. Complementary tests for selection of the physical layer technology, development of the necessary adaptations and extensions to the transport layer specification, subjective assessment of the video coding quality (determination of the necessary bitrate), development of adaptations and extensions of the Application Coding, and other activities are expected to be developed until 2023 [7].

Nonetheless, the availability of spectrum resources for DTT Services is declining worldwide, especially in the UHF Band. The 700 MHz band is already globally harmonized for the deployment of IMT Services and the 600 MHz band is also being considered in many countries for services rather than DTT. Furthermore, there is an intense debate for the next ITU-R World Radiocommunication Conference over the full review

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The information and views set out in this paper are those of the authors and do not necessarily reflect the official opinion of the institutions with which they are affiliated.

[1]The information about candidate technologies can be found at https://forumsbtvd.org.br/tv3_0/

http://www.set.org.br/ijbe/ doi: 10.18580/setijbe.2022.2 Web Link: http://dx.doi.org/10.18580/setijbe.2022.2

of the frequency band 470-694 MHz in ITU Region 1 [8], which includes Europe, Africa, the northern part of Asia, and part of the Middle East.

This paper analyzes the current and the future spectrum usage of television services in Brazil to develop realistic transition models approaches for the deployment of Next Generation Digital Television Services. In Section II, we begin by analyzing the current spectrum usage of digital television in Brazil. Next, in Section III, we discuss tendencies for UHF and VHF Band usage for DTT Systems in near future and we discuss some transition policies for next-generation digital television systems. Lastly, in Section IV, we draw some conclusions.

II. Current Spectrum Usage of Television Services in Brazil

The first phase of the transition from analog to digital terrestrial television broadcasting in Brazil was successfully completed in January 2019. It has included 1,379 municipalities (129.6 million inhabitants, 62.6% of the Brazilian population), including all state capitals, metropolitan areas, and other areas where the analog switch-off was required to clear the 700 MHz band. For the rest of the country (77.3 million inhabitants, 37.4% of the population, distributed in 4,191 municipalities), it is expected that the analog television switch-off will be completed at the end of 2023[9] [10].

Since the introduction of DTT services in Brazil, in the middle 2007, about 19,721 digital channels were planned and included in the Brazilian Master Register for Digital Television Channels, a database for broadcasting channels managed by the National Agency of Telecommunications (Anatel) [11]. Figure 1 shows the current distribution of DTT channels in Brazil.

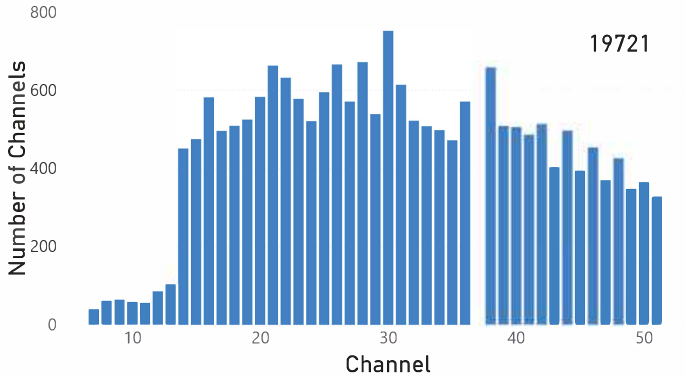

Fig. 1: Distribution of Digital TV Channels in Brazil.

To evaluate spectrum usage of TV Services in the Brazilian territory, simulations were made to estimate the coverage of all operating channels. The applied methodology is described in the following subsections. The web-based spectrum management software, Mosaico (based in Spectrum-E), has been provided through the courtesy of Anatel for the calculations.

A. Database Analysis

Determining the number of operating stations in Brazil is challenging. National policies were established in the past to allow broadcasters to start transmissions even before getting a formal license by Anatel [12]. It has promoted a fast process for installing new DTT channels because broadcasters were able to provide services by only paying radio frequency usage fees and just starting the required application for obtaining the license. However, many broadcasters had started licensing process and did not install transmission sites or, on the opposite - they had installed transmission sites and did not finalize the licensing process. The result is that only 43% of authorized digital stations are currently licensed [11]. However, this number does not reflect the real number of operating stations in Brazil.

To achieve better accuracy of coverage simulations, it is primordial that the database of DTT stations reflects as precisely as possible the currently operating ones. Considering that a database of operational DTT stations is unavailable, as mentioned before, we have made some assumptions to retrieve data from Anatel's database source. We consider that all registers containing at least a valid DTT authorization act issued by the Ministry of Communications, and an assigned radio frequency act published by Anatel, configure an operational station. These documents were considered for selecting stations due that without both of them Brazilian broadcasters are not able to start transmissions. The obtained result is that 12,711 DTT channels (about 64,45% of the total number of planned channels) are estimated to be operational in Brazil. Figure 2 and Figure 3 show the distribution of the estimated operative DTT Channels in Brazil and comparative percentage, respectively:

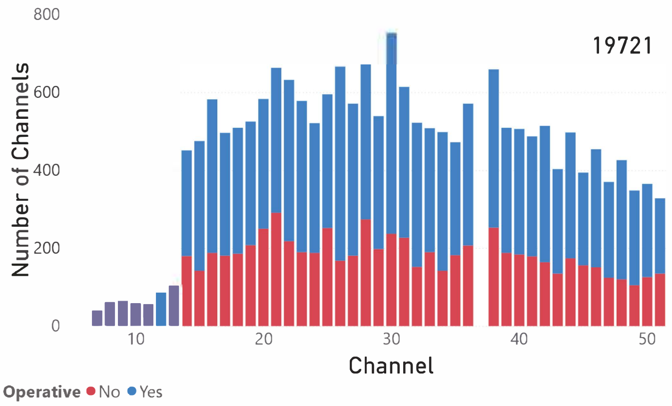

Fig. 2: Distribution of Operative Digital TV Channels in Brazil.

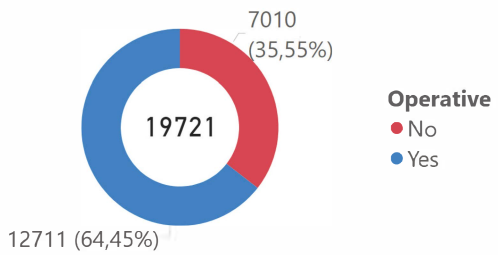

Fig. 3: Percentage of Operative Digital TV Channels in Brazil.

Secondly, as few of the total DTT Channels are currently licensed, the availability of technical data containing the necessary inputs for simulating the estimated coverage is scarce. It occurs because only by completing the registration of the station's parameters (antenna height, radiated diagram, ERP, etc) technical data can be retrieved from Anatel's database.

So, once again, some approximations were considered. For simulating all predicted coverage, an algorithm from Mosaico software that simulates an ideal station was applied. This algorithm calculates the best antenna diagram and ERP for a station in a determined location. It takes the maximum protected contour, determined by Anatel Technical Regulation [13], and terrain data to perform calculations. The result is that for each channel it is created an ideal station that could reach the maximum protected contour in each direction, from 0 to 360 degrees with a 1-degree step. Figure 4 and Figure 5 show the calculated antenna pattern in different types of terrain profiles. The protected contours are plotted in those figures using Recommendation ITU-R P.1546-5 [14], which is the reference prediction method for determining the maximum protected area of a DTT station, as defined by Anatel [13].

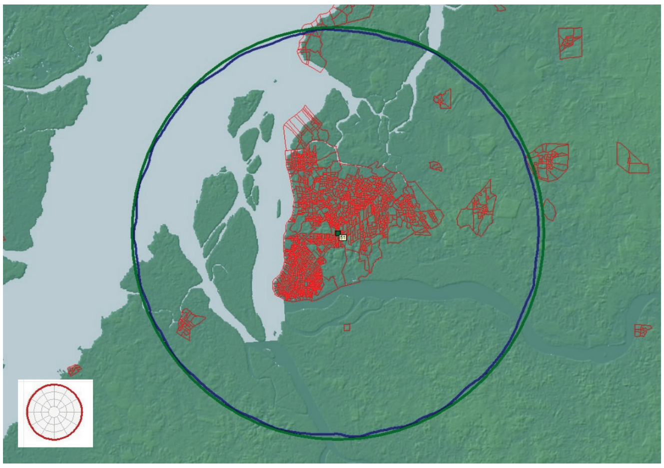

Fig. 4: Example of a computed antenna pattern in flat terrain.

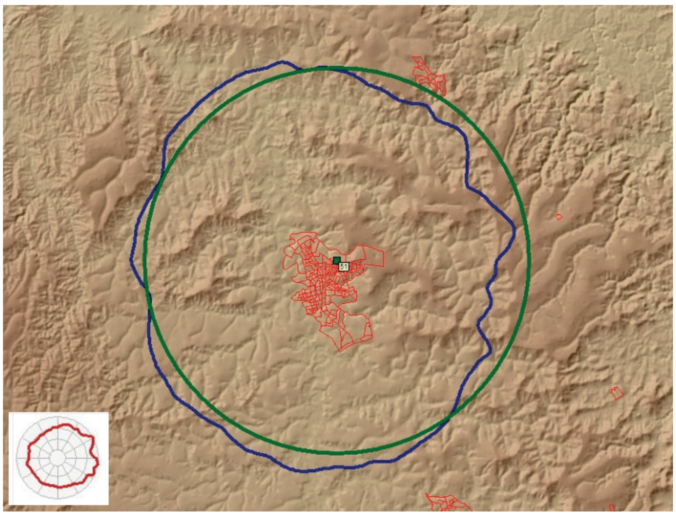

Fig. 5: Example of a computed antenna pattern in rough terrain.

B. Simulation Parameters

The estimation of the coverage of DTT stations involves frequency management aspects and databases with equipment-related information; accurate knowledge of terrain data where the system is to be deployed; and detailed information on the distribution of the population inside the service area [15]. In addition, the nature of the propagation model in use will be of paramount importance for realistic predictions and efficient and precise network dimensioning [15].

TABLE I: ITU-R P.1812 simulation parameters

Parameter	Value
Receiving Height	10 m
Calculated Distance	100 km
Percentage of time	50 %
Percentage of locations	50 %
Subpath	Delta Bullington
Clutter Resolution	Default
Terminal Clutter Losses	Not considered
Profile Sampling	1,000 points

As mentioned before, the web-based spectrum management software, Mosaico, was used to estimate the coverage of all 12,711 operating DTT channels in Brazil. The software makes available various propagation models for DTT coverage estimation. For the purpose of the present article, the Recommendation ITU-R P.1812-5 was chosen. This ITU-R Recommendation provides a deeper consideration of potential propagation phenomena and it will provide more accurate path loss results in some specific links. In consequence, ITU-R states that P.1812 should be used for the detailed evaluation of point-to-area signal levels[16] [15].

Furthermore, ITU-R P.1812 is a modern recommendation (last updated in August 2019) and the ease of reproducibility of results and implementation transparency of the ITU-R P.1812 model can allow for a better degree of standardization of a propagation prediction method for point-to-area terrestrial services in the VHF and UHF frequency bands [17]. Parameters of Table I were used to achieve a balance between speed and accuracy of the simulations.

Finally, to determine the service area it was considered the minimum field strength defined by Anatel on its technical rule: $51 dB\mu V/m$ for channels in the UHF band and $43 dB\mu V/m$ for channels in the VHF Band (see Table 1 in [13]).

C. Results

After establishing all the required parameters, simulations were made to predict the service area of all considered DTT stations. Figure 6 illustrates the predicted coverage of channel 20 in a part of Brazil.

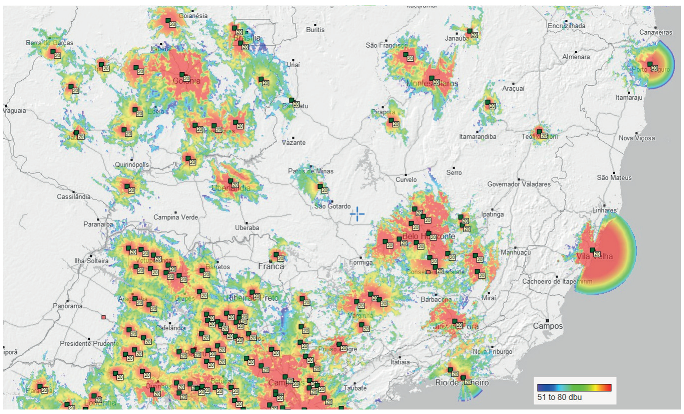

Fig. 6: Example of predicted coverage for DTT Channel 20.

The population distribution inside the service area was calculated considering the percentage of coverage on each sector of the census geographic boundary shapefiles provided by the Brazilian Institute of Geography and Statistics [2]. A municipality was considered covered by a DTT station when at least 90% of its urban population is inside the predicted coverage area. A high coverage percentage was chosen because the predictions are overestimated by the assumptions made to compute ideal antenna patterns and also because the used software automatically reduces terrain resolution on networks with a large number of entries.

Simulations were made considering the current DTT channel distribution. However, until December 2023, analog television will remain operative, as mentioned before. Applying the same estimation methodology, it is estimated that 9,230 analog TV stations are still operative. Most of these stations are allocated in the VHF band as shown in Figure 7.

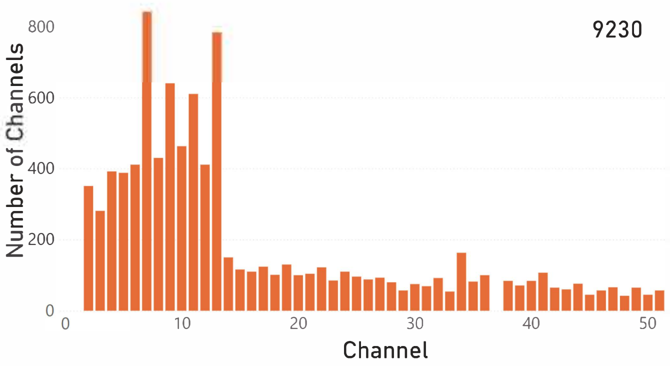

Fig. 7: Distribution of Analog TV Channels in Brazil.

The same methodology for predicting DTT coverage was also applied to simulate the coverage of those estimated operating analog TV stations. The considered minimum field strength, however, differs from digital to analog TV, as stated in Anatel's technical rules. It was used $58 dB\mu V/m$ for channels 2 to 6, $64 dB\mu V/m$ for channels 7 to 13, and $70 dB\mu V/m$ for channels in the UHF Band (see Table 1 in [13]). Figure 8 shows the number of municipalities covered by Analog TV or Digital TV Channels.

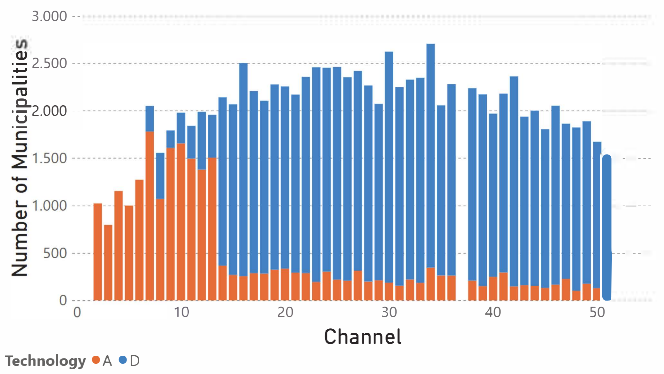

Fig. 8: Number of municipalities covered by Analog TV (A) and Digital TV (D) per channel in Brazil.

The numerical results of the coverage simulations of digital and analog operating stations are summarized in Tables II and III. One table is the opposite of the other: Table II contains the number of municipalities covered by at least one TV channel (digital, analog, or any of them) and Table III has the number of municipalities with no TV coverage (digital, analog, or none of them). Results were also classified by frequency band: sea

[2]Based in 2010 census, available at https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/26565-malhas-de-setores-censitarios-divisoes-intramunicipais.html?=&t=downloads

TABLE II: Number of municipalities covered per frequency band

Frequency Band	**Municipalities with at least one digital channel**	**Municipalities with at least one analog channel**	**Municipalities with at least one channel**
All Bands	5312 (96.27%)	4210 (75.57%)	5418 (97.32%)
VHF A Channels 2 - 6	0 (0.00%)	2691 (48.31%)	2691 (48.31%)
VHF B Channels 7 - 13	946 (20.36%)	3800 (67.99%)	4042 (72.73%)
UHF A Channels 14 - 36	5179 (94.47%)	2510 (44.45%)	5232 (95.01%)
UHF B Channels 38 - 51	4417 (81.69%)	1508 (26.61%)	4565 (83.70%)

TABLE III: Number of municipalities with no reception per frequency band

Frequency Band	**Municipalities with no digital channels**	**Municipalities with no analog channels**	**Municipalities with no channels**
All Bands	258 (4.63%)	1360 (24.42%)	152 (2.73%)
VHF A Channels 2 - 6	5570 (100%)	2879 (51.69%)	2879 (51.69%)
VHF B Channels 7 - 13	4624 (83.02%)	1770 (31.78%)	1528 (27.43%)
UHF A Channels 14 - 36	391 (7.02%)	3060 (54.94%)	338 (6.07%)
UHF B Channels 38 - 51	1153 (20.70%)	4062 (72.93%)	1005 (18.04%)

- VHF A: Channels 2 - 6 (55 - 72 MHz ; 76 - 88 MHz);
- VHF B: Channels 7 - 13 (174 - 216 MHz);
- UHF A: Channels 14 - 36 (470 - 608 MHz);
- UHF B: Channels 38 - 51 (614 - 698 MHz).

A straightforward finding that can be extracted from data analysis is that digital television has huge penetration in Brazil. As shown in Table II nearly 96% of the Brazilian municipalities can receive at least one DTT channel. Until the end of the analog switch-off, penetration may reach almost 100%. On the other hand, analog TV is still covering about 75% of the municipalities, which shows the importance of well-defined policies for switching-off analog television.

Besides DTT penetration is undoubtedly remarkable in Brazil, the diversity of channels is not so high. Approximately half of the Brazilian municipalities have less than 11 DTT channels, and about 13% have no more than 2, as shown in Figure 9.

Geographically, the Brazilian States from the North, Mid-west, and Northwest regions are the ones with a fewer average of received DTT channels. Figure 10 shows the average of received DTT channels per Brazilian State and Figure 11 contains a map view of the results.

Table II and Figure 8 also show that analog and digital TV occupy spectrum sub-bands distinctively. Analog TV is concentrated on the VHF Band and DTT on the UHF Band. Historically, analog television was first implemented in Brazil in the VHF Band, which partially explains why UHF Band was

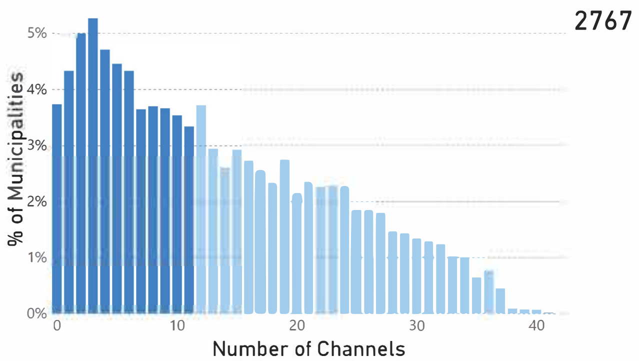

Fig. 9: Percentage of municipalities covered per number of channels in each municipality in Brazil.

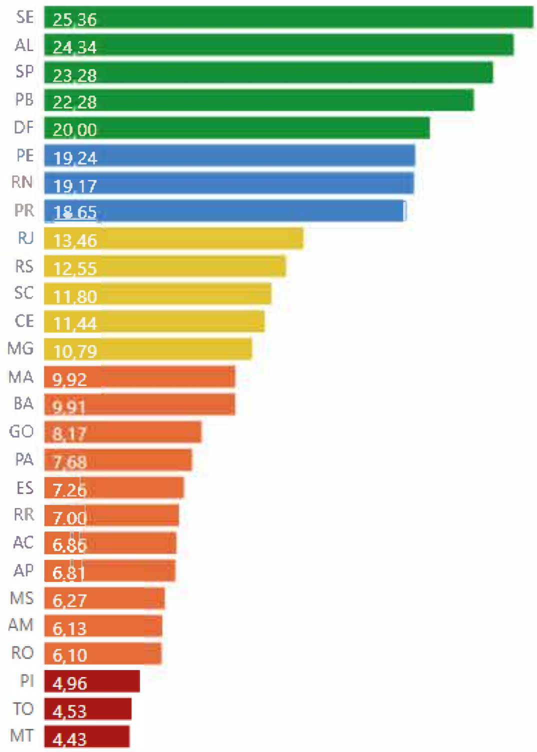

Fig. 10: Average of received DTT channels per Brazilian State: red (less than 5), orange (from 5 to 10), yellow (from 10 to 15), blue (from 15 to 20), and green (more than 20 channels).

Fig. 11: Map view - Average of received DTT channels per Brazilian States: red (less than 5), orange (from 5 to 10), yellow (from 10 to 15), blue (from 15 to 20), and green (more than 20 channels).

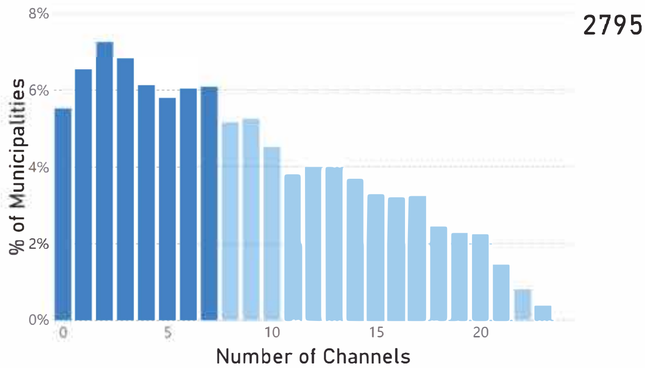

Fig. 12: Percentage of municipalities covered per number of channels in the UHF A Band.

preferable for DTT deployment. Furthermore, the susceptibility of some configurations of DTT systems to impulsive noise, more relevant in the lower frequencies, was found by the tests carried out in Brazil in 2001 for defining the Brazilian first-generation DTT system [18].

DTT coverage in Brazil, as mentioned, is concentrated in the UHF band. In particular, the UHF A Band (Channels 14 - 36, 470 - 608 MHz) has a high density of received channels. Figure 12 contains the distribution of the number of received channels in the UHF A Band. It shows that considering the number of received channels per municipality in the UHF A Band, about 50% have no more than 7 DTT channels. In other words, in half of the municipalities in Brazil, at least about 70% of the total amount of spectrum availability of the UHF A band (16 from 23 channels) is currently not being used.

Almost the same behavior occurs in the UHF B band (Channels 38 - 51, 614 - 698 MHz). Despite in about 82% of the municipalities this band being used by at least one DTT channel, about 48% of the municipalities have no more than 3 channels. So, at least 78% of the total amount of spectrum availability of the UHF B band (11 from 14 channels) is not being used in more than half of the municipalities in Brazil. Figure 13 shows the distribution of the number of received channels in the UHF B Band.

Availability of spectrum, however, depends also on the evaluation of the denied spectrum that a TV station produces. The fact that a determined channel is not being used in a municipality does not imply that it is viable to be used. Protection ratios between co-channel and adjacent channels are defined by Anatel [13] (Table 4). So, for a complete evaluation of spectrum availability, it is necessary to develop sharing studies between the operating TV channels and possible new radiocommunications services, considering the protection criteria and minimal field strength for the operation of the services.

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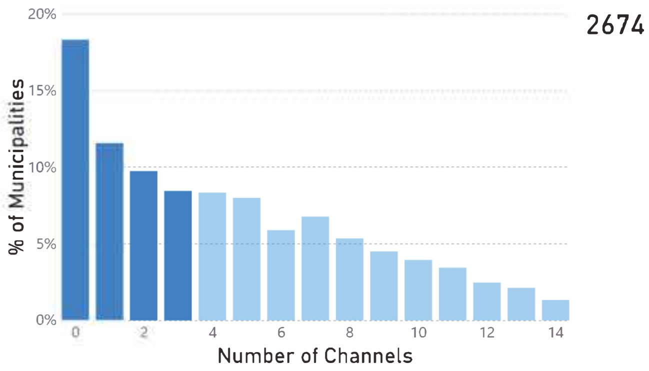

Fig. 13: Percentage of municipalities covered per number of channels in the UHF B Band.

III. Future Spectrum Usage

In Section II we showed how spectrum is currently being used by television services in Brazil, based on coverage simulations of all TV stations that are estimated to be in operation. However, spectrum usage is dynamic and changes practically everyday. In Brazil, there are clearly defined spectrum policies that directly impact television services for the next years. Furthermore, new technologies will certainly drive new possibilities for spectrum usage. The next subsections describe envisaged spectrum policies that can affect the provision of DTT in Brazil.

A. *Spectrum Usage After the Analog TV Switch-off*

As mentioned in Section II, television analog switch-off is expected to be completed in Brazil by the end of 2023. So, it is estimated that all 9,230 analog stations (see Figure 7) will soon no longer be operative, impacting 4,210 municipalities (75.58%) that receive at least one analog channel, as shown in Table II. A direct impact of the analog switch-off is that spectrum usage of the VHF Band will suddenly decrease, considering that about 65% of analog TV channels are operating in this band, as shown in Figure 14. The impact o UHF Band usage will also be relevant - 3,225 analog channels in this band will also cease operations.

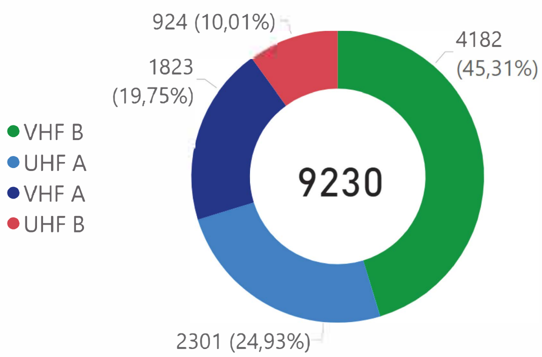

Fig. 14: Number (Percentage) of operative analog TV channels per frequency band.

On the other hand, as shown in Figures 2 and 3, there is a huge number of planned DTT channels (7,010) that are currently not operative. From this total amount, analysis of the data obtained from the Ministry of Communications by means of the Brazilian "Right to Information Law" [19] indicates that 3,229 channels (46%) will not begin operation in the short or mid-term. These channels were reserved for public policies that were not initiated or concluded (for educational and public broadcasting), or were planned for transitioning analog TV channels for digital operation, but were not used. The other 3,781 channels (54%) are mainly located in regions where simulcasting is still ongoing and clear public policies have already been defined.

Specifically for these regions, the Brazilian Ministry of Communications established in 2021 a government program to facilitate the transition for DTT [20]. The main objective of the program is to install complete shared DTT transmission sites in 1,638 small municipalities where only analog TV stations are operative. Besides transitioning current analog TV channels, the program also provides rules for expanding the variety of TV content for the population by adding two new DTT channels (up to 8 different TV programs) on each transmission site for public broadcasters. Funding for the program is provided by resources from the 700 MHz band auctioning process for 4th generation IMT Advanced Systems, which account for approximately R$ 850 million (US$ 160 million) specifically reserved as counterparts for the digital dividend [21].

To accomplish the task, a huge spectrum planning process for including new DTT channels has been carried out by Anatel. Analyzing Anatel's database from April 2021 to May 2022, it was planned 4,661 channels in the 1,638 municipalities of the public program. The effective operation of the channels, however, depends on qualifying analog TV broadcasters and the municipalities, considering the requirements established in Chapter II [20].

So, channels located in those 1,638 municipalities have a higher probability of starting operating, as public policies for funding transmission sites have already been established. Data analysis also indicates that some channels were recently included by request of broadcasters that wish to expand their existing DTT coverage. These channels were also considered to have a high probability to be licensed sooner and starting operating. Figure 15 summarizes the obtained results:

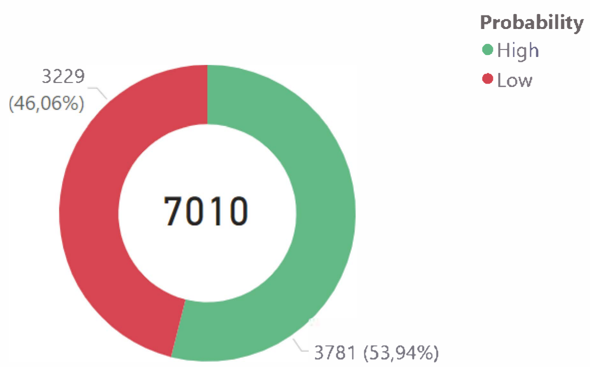

Fig. 15: Number of DTT Channels that are not operatively classified by probability to start operation in the short-term.

Lastly, the conclusion is that besides 9,230 analog channels will soon cease operations with the analog switch-off in Brazil,

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about 4 thousand new DTT channels are expected to start transmission in the short-term. Hence, DTT channel distribution in Brazil after the analog switch-off is expected to contain about 16,492 operative channels as illustrated in Figure 16.

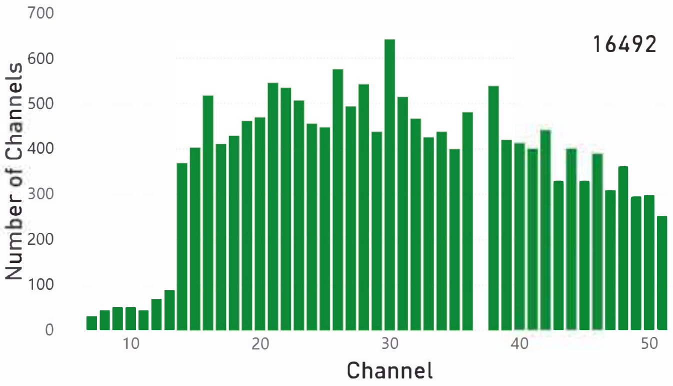

Fig. 16: Expected distribution of Digital TV Channels in Brazil after the analog switch-off.

The next subsection contains the impact of these channels on the transition to Next-Generation DTT Systems in Brazil.

B. Spectrum availability for Next-Generation DTT Systems

The analog switch-off will release huge portions of spectrum, specially in the VHF band, as mentioned in the last subsection. In Brazil, VHF A band is not used for DTT as defined in the technical regulation normative [13]. So, VHF channels 2 to 6 (54 - 72 MHz; 76 - 88 MHz) will be completely released from television services after 2023.

In addition, currently there are no defined public policies for broadcasting services in the band of channels 2 to 4 (54 - 72 MHz). This band is being considered for the usage of TV White Spaces (TVWS) [22]. Public policies for the usage of channels 5 and 6 (79 - 88 MHz), however, have already been established in Brazil for FM broadcasting services by means of a presidential decree [23]. Further, technical parameters for channel planning on this band were established by Anatel in [24] and [25].

SBTVD Forum studies are also not considering VHF A Band for the deployment or Next-Generation TV Systems in Brazil. TV 3.0 over-the-air physical layer is to consider that it should, in principle, be deployed in the bands currently allocated for DTT in Brazil (High-Band VHF and UHF), using the 6 MHz channel raster and it should co-exist with adjacent ISDB-Tb channels for a long time without mutual interference [6]. Hence, only VHF B and UHF Band will be available for DTT services.

Considering the expected DTT channel distribution in VHF B and UHF Bands, as shown in Figure 16, coverage simulations were computed to estimate the spectrum usage after the analog switch-off in Brazil. Figure 17 shows the number of municipalities covered by at least one DTT Channel. Numerically, the results are presented in Table IV.

To better evaluate the expected spectrum availability in a determined region, a spectrum index (I) was computed by normalizing the total number of received channels in the ith municipality (R_i) with the total number of allocated channels for DTT services (A), as showed in Equation 1.

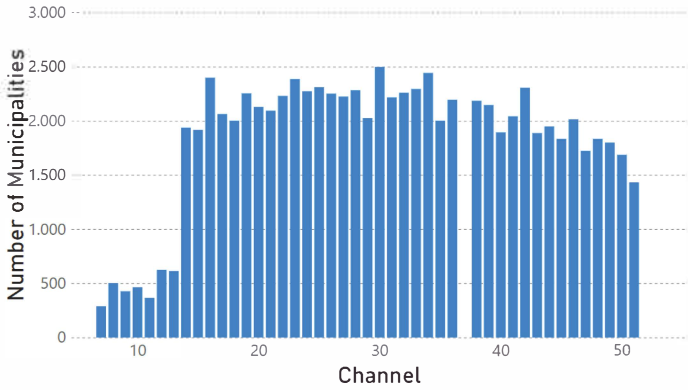

Fig. 17: Number of municipalities covered by at least one DTT Channel.

TABLE IV: Number of municipalities with at least one digital channel per frequency band.

Frequency Band	**Municipalities with at least one digital channel (percentage)**
All Bands	5398 (96.91%)
VHF B (Channels 7 - 13)	1502 (26.97%)
UHF A (Channels 14 - 36)	5334 (95.76%)
UHF B (Channels 38 - 51)	4724 (84.81%)

$$I = \sum_{i=1}^{N} \frac{R_i}{A} \tag{1}$$

in which:

A = total number of allocated channels for DTT services
R_i = number of received channels in the ith municipality
N = number of municipalities

Considering the available channels between channels 7 to 51, $A = 44$. So, applying the methodology of Equation 1 it is possible to obtain the spectrum index I in all Brazilian municipalities. Results are geographically illustrated in Figure 18.

An important conclusion that can be drawn from the results shown in Figure 18 is that besides there is a huge number of municipalities where the spectrum occupancy in VHF B and UHF Bands is not high (green areas), the main metropolitan regions (yellow and red areas) are densely used by DTT services. These regions concentrate about 73% of the Brazilian population. Hence, new approaches for transitioning to Next Generation Television Systems should be considered. The next subsection contains some proposed transition policies based on the above-mentioned results.

C. Transition Policies for TV 3.0

As could be found in the coverage analysis, spectrum occupancy of DTT services is not uniformly distributed. Some regions in Brazil have a high number of received DTT channels and others lack of it. Figure 18 was classified into three regions: $I \leq 0.3$ (green), $0.3 < I < 0.6$ (yellow) and $I \geq 0.6$ (red).

http://www.set.org.br/ijbe/ doi: 10.18580/setijbe.2022.2 Web Link: http://dx.doi.org/10.18580/setijbe.2022.2

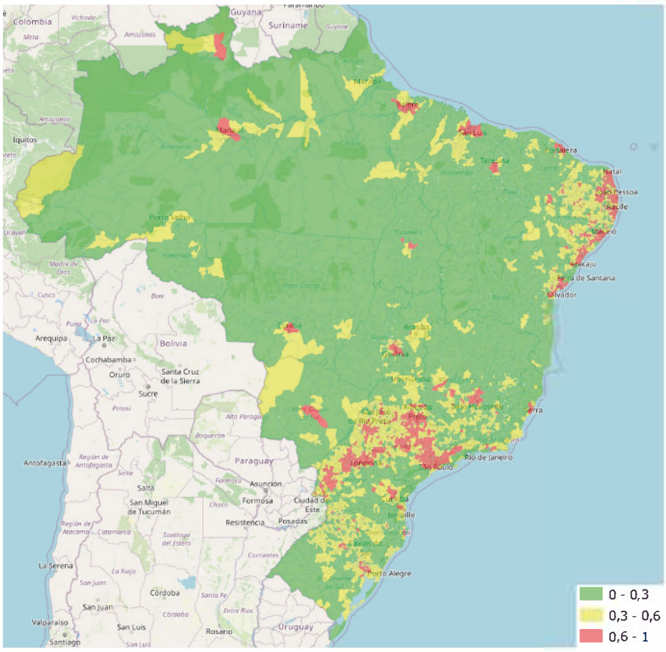

Fig. 18: Spectrum index I per Brazilian municipality.

Ideally, a smooth transition to TV 3.0 would require an additional 6 MHz channel for the transmission of new digital carriers, as there is no general requirement for backward compatibility with first-generation systems, as mentioned in Section I. So, regions where $I \leq 0.5$ in principle would allow simulcasting of first and second generation of DTT systems. However, to avoid interference in zones where spectrum occupancy is higher and facilitate channel planning, establishing a margin would be advisable. So, the $I \leq 0.3$ (green areas of Figure 18) was considered to identify regions where there is sufficient spectrum availability and, consequently, transition policies would be effortless.

For $0.3 < I < 0.6$ (yellow areas of 18) transition for TV 3.0 requires specific policies as it would not be possible to reserve additional 6 MHz channels for the transition of all operative DTT channels. This is a scenario that is currently occurring in the transition for ATSC 3.0 in the United States, as UHF spectrum availability for DTT services has declined after the conclusion of the incentive auction made by the Federal Communications Commission (FCC) to repurpose the 600 MHz Band for both licensed use and unlicensed use [3]. So, because a TV station cannot, as a technical matter, simultaneously broadcast in both ATSC 1.0 and ATSC 3.0 format from the same facility on the same physical channel, FCC has established that local simulcasting must be effectuated through voluntary partnerships that broadcasters seeking to provide Next Gen TV services enter into with other broadcasters in their local markets [26].

Hence, American TV broadcasters are being encouraged to share their facilities in order to implement ATSC 3.0 and also keep ATSC 1.0 transmissions from other partners to minimize the impact on viewers that still do not have ATSC 3.0 receivers. In Brazil, a similar approach should be adopted. TV 3.0 requirements do not include backward compatibility with ISDB-Tb, so, especially in regions where $I > 0.3$, shared transmissions will be required to enable the transition of all broadcasters.

A more challenging situation is to enable transition for TV 3.0 in regions where I is greater than 0.6. In these regions, even sharing facilities may not be sufficient to keep simultaneous transmissions between ISDB-Tb and TV 3.0. Thus, it is required to establish policies to promote direct transition to TV 3.0 in the same 6 MHz channel by switching-off ISDB-Tb transmissions of some broadcasters. To exemplify the transition complexity according to the classified municipalities shown in Figure 18, three cities with different spectrum indexes are included in Figure 19. White slots represent possible channels that can be used for the transition to TV 3.0.

Fig. 19: Example of cities with different spectrum indexes I. White slots represent possible channels that can be used for the transition to TV 3.0. The graphs are colored according to the subtitle of Figure 19.

São Paulo city is a clear example where few empty channels are available for the transition to TV 3.0. It is expected that only 9 slots are suitable for the transition of the expected operating DTT Channels. So, switching-off ISDB-Tb transmissions of some broadcasters will be needed to promote TV 3.0 in the region. Brasilia is an example of a lower complexity city, but sharing infrastructure may be required. Porto Seguro, on the other hand, is an example of a green region where the spectrum availability is sufficient to enable simulcasting ISDB-Tb and TV 3.0.

It is also important to highlight that new DTT channels are expected to begin operations in the mid and long-term (see Figure 15 and consequently increase the spectrum index in some municipalities. Two main policies are imminent: repressed demands for new relay stations and the usage of idle capacity of the facilities installed under the Ministry of Communications Program created by the act [20]. So, the total number of operative DTT channels may vary during a transition to TV 3.0.

So, the spectrum index analysis shows that hybrid approaches should be implemented to introduce new digital television systems in Brazil. Some proposed policies to facilitate the transition to TV 3.0 are listed below:

- ***Reserve High-VHF Band (Channels 7 to 13) for the transition to TV 3.0***. After the analog switch-off, the High-VHF Band will be released in most municipalities. Furthermore, the CfP for TV 3.0 in Brazil includes the

[3]See https://www.fcc.gov/wireless/bureau-divisions/broadband-division/600-mhz-band

http://www.set.org.br/ijbe/ doi: 10.18580/setijbe.2022.2 Web Link: http://dx.doi.org/10.18580/setijbe.2022.2

requirement that the Over-the-air Physical Layer should consider the deployment in this band. Hence, updating the regulation to reserve the band would bring the benefit of having a specific spectrum portion to deploy next-generation DTT networks.

- ***Re-plan current DTT channels in some areas to free continuous spectrum portions***. Current DTT channels were planned in a simulcast scenario where analog TV channels had to be protected to guarantee a smooth transition. So, the planning process was not optimized. Channeling optimization would promote spectrum efficiency and release parts of the UHF spectrum for the deployment of next-generation DTT networks.
- ***Update regulation to allow multi-programming***. The current Brazilian regulation just allows public broadcasters to transmit more than one program in a single 6 MHz channel. However, due to the high utilization of the UHF band by 1st generation DTT transmissions, it will not be possible to allocate a second 6 MHz channel for all broadcasters for the transition to next-generation DTT Systems, mainly in Brazilian state capitals regions and high dense metropolitan areas. So, multi-programming will be necessary to optimize spectrum usage and facilitate the transition.
- ***Promote installation of shared infrastructure***. DTT was implemented in Brazil in a selfish way. Broadcasters have taken advantage of their current analog TV infrastructure to install DTT transmission sites on their own, doing the transition channel by channel. So, there are a few unbidden initiatives in Brazil where DTT transmission sites were shared by more than one broadcaster. Recent public policies have been established to install complete shared DTT transmission sites in small municipalities to facilitate the transition from analog to digital television, but more incisive policies are required for the deployment of shared next-generation DTT transmission sites.
- ***Promote the production of TV sets with ISDB-Tb and TV 3.0 receiving capability as soon as the system technology has been defined***. The spectrum availability analysis has indicated that in many regions there will be no sufficient channels for simulcasting both generations of DTT systems. Hence, a strong policy for the production of TV sets with TV 3.0 receiving capability will be required to accelerate the replacement of the current digital television receivers and minimize the impact on viewers.

IV. Conclusions

This paper presents important contributions to the transition to TV 3.0 in Brazil. It presents coverage simulations results using Recommendation ITU-R P. 1812 that quantifies the spectrum availability in the 174-216 MHz VHF band and 470-698 MHz UHF band. Simulations were made considering also the expected deployment of new DTT channels, based on the assessment of Anatel's database and public policies that have been established by the Ministry of Communications.

Three categories of regions were defined based on their spectrum availability, which was calculated considering the number of receiving DTT channels that were predicted by coverage simulations. Results indicate that in the main metropolitan regions, where concentrates most of the Brazilian population (about 73%), there will be no spectrum availability after the analog TV switch-off for simulcast transmissions between the current ISDB-Tb System and the future TV 3.0. So, hybrid approaches should be implemented to introduce a new digital television system in Brazil.

Furthermore, some policies are proposed to facilitate the transition: reserve High-VHF Band (Channels 7 to 13) for TV 3.0, re-plan current DTT channels in some areas to free continuous spectrum portions, update regulation to allow multi-programming, promote the installation of shared infrastructure and promote strong policies for the production of TV sets with TV 3.0 receiving capability as soon as the system technology has been defined.

As future works, we envisage simulating the estimated denied spectrum generated by DTT channels considering co-channel and adjacent channel interference field strength to optimize DTT frequency planning and better identify areas where spectrum can be used for facilitating the introduction of TV 3.0. Furthermore, we identify that simulations contain conservative values due to software restrictions for the prediction of a high number of channels. So, we consider repeating simulations to have better coverage resolution. Finally, we intend to develop methods to gather better information from Anatel's database about the technical parameters of DTT stations, as database assumptions were made in the present paper to estimate the number of operative DTT channels.

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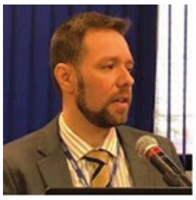

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Received in 2022-06-06 | Approved in 2022-07-25