Testing ISDB-Tb Digital TV Receivers

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Abstract— **The introduction of digital TV in Uruguay, adhering to the ISDB-T standard as many South American countries, is beginning: channels were assigned and the decoders and receivers are being imported, because the Uruguayan market size is not sufficient to manufacture them locally. The government decided to test the receivers for compliance with the standards, and this task was committed to Facultad de Ingeniería, Universidad de la República (UdelaR) and Centro de Ensayos de Software (CES). This article reports the key aspects of this work: the analysis of the standards, the definition of a type approval protocol, and concludes with an overview on the existing agreements in the ISDB-T community. Currently, the protocol is well defined for signal reception (sensitivity, modulation modes, decoding, video and audio formats). In contrast, the existing implementations are not compatible regarding interactivity, and therefore a set of universal tests would be very restricted. In fact, in this work a common set of commands was searched, but the conclusion is that it would be too scarce to implement useful or appealing applications. The evolution and unification of the standard is an important task to perform. Local companies (software and audio visual branches), broadcasters and local academies need to follow actively this evolution and contribute to it.**

I. Introduction

The deployment of terrestrial digital television has technical and socio-political implications: it promises a better signal quality and higher spectral efficiency, which can in turn give place to a greater cultural diversity in the content creation and distribution. Uruguay, following Brazil's leadership in the South American continent, has chosen the Integrated Services for Digital Broadcasting, Terrestrial, Brazilian version (ISDB-Tb) standard, defined by Associação Brasileira de Normas Técnicas (ABNT) [1]. Even though Uruguay has a quite high Internet penetration, covering about 48% of homes, television is still very important because in almost 92% of them there is at least one receiver, and roughly 61% are cable television subscribers [2]. The open signal is, still, a key factor for social integration, especially in suburban and barely populated rural areas.

Trial broadcasting began in late 2012, while the receivers were just starting to be available. Uruguayan market is very small, and therefore both Set-Top Boxes and TV sets need to be imported. The Dirección Nacional de Telecomunicaciones (DINATEL) [3] has ruled the condition of testing and certifying the receivers in a national laboratory, recruiting UdelaR and its partner institution, CES [4], to collaborate in the definition of the test suite. CES is a joint venture between UdelaR and Cámara Uruguaya de Tecnologías de la Información (CUTI), devoted to software testing and homologation, and therefore, its participation in this project guarantees that proper procedures are followed in the testing process. One may ask why to test and certify TV receivers, being domestic appliances manufactured under a defined standard. There are three kinds of reasons: to begin with, there is scarce previous experience and different deployment conditions than in Japan (where the ISDB-T standard was first implemented), Brazil and Argentina. Therefore, to help the local deployment, the government is especially interested in orienting people to buy receivers compatible with the standard. On the second place, the intuition that, having two different countries (Brazil and Argentina) implementing the standard with different objectives and strategies, some aspects should be carefully tested; this proved to be true, and after in-deep analysis and testing, which are described in this article, it was found that the standard has different and not fully compatible versions, especially regarding interactivity. And third, the political intention of fostering the software and audiovisual industries, which foreseen deployments are heavily based on the interactive aspects of the standard. Those branches are important in Uruguay, which is the leading per-capita software exporter of South America [5], while audiovisual, among other cultural industries, is in fast developing and was responsible for about 0.45% of the GDP in 2011 [6] and is now more than 1%.

The ISDB-Tb standard has two major aspects: interactivity, and signal reception and decoding. Interactivity, implemented by a Brazilian middleware named Ginga, is expected to be an important component of public campaigns, advertising and on-line games. Its foreseeable users are the government (social development, health and culture ministries, among others), broadcasters, and commercial companies.

Regarding signal reception and decoding aspects, in this work the main features to be tested were analyzed. Test analysis leads to the conclusion that the theoretical set of exhaustive tests should be pruned. Indeed, the standard allows multiple configurations, not only in source coding, but also in channel coding, modulation and transmission; testing every combination would be non feasible in the real world. However, during the testing process it has been found out that many receivers did not support some of these configurations. The aim of this work was in this sense to achieve a represen-

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tative subset of tests which would guarantee a right receiver operation. Finally, the transmission requirements, established in the coverage regulation, were compared with the reception requirements, such as the receiver sensitivity, in order to determine guidelines for the receivers' installation. This part of the work corresponds to Section II.

Regarding interactivity aspects, a thoughtful analysis was done taking into account Ginga standard documents and existing implementations form Brazil and Argentina. Important differences among the implementations were found and, more important, none of them is fully compliant with the standards. In some cases there are different understandings, while in many aspects there are clear deviations from the standard. Some bugs were identified, that should be corrected. This kind of results, and a comparison between implementations and the standard, is the contents of Section III.

In Section IV, the current situation of the homologation of receivers is referred, while in Section V the conclusions are summarized and some foreseen further work is pointed out.

Throughout this document the abbreviations ISDB-T and ISDB-Tb are distinguished. The first one refers not only to the original version of the standard, the Japanese version, but also to its international version defined in the International ISDB-T Forum. See, for example, [7]. The second one is used to refer only to the Brazilian version which unlike the original one, uses MPEG-4 [10] [11], instead of MPEG-2 for video and audio compression and uses Ginga as interactivity middleware instead of BML.

II. Signal reception and decoding aspects

A. What to test: system description

The ISDB-T transmission system can be configured in many different ways regarding channel coding and modulation in order to prioritize useful bit rate or noise immunity. Such is the case of modulation mode, guard interval, convolutional code, time interleaving, etc. Source coding is also important to be defined in every multimedia broadcasting system; ISDB-Tb uses MPEG-4 as audio and video compression standard. Finally, automatic channel tunning, sensitivity, co-channel and adjacent channel interference, and other functionalities have also to be tested. Even though the ISDB-Tb transmission and reception systems are entirely defined in documents [12] and [13], almost every test was defined based on [14]. This document was taken as reference because it summarizes the binding agreements reached by the international ISDB-T community.

ISDB-T uses OFDM modulation in a $6MHz$ channel. This channel is divided into 13 sub-channels named "segments", each segment has a bandwidth of $\frac{6}{14}MHz \approx 428.57kHz$. The remaining sub-channel is used as guard interval at the sides of the OFDM spectrum. It is interesting to note that the segments can be grouped in up to three hierarchical layers named "A", "B", and "C". Each hierarchical layer carries different media contents; since each layer has a different convolutional code rate, time interleaving and modulation scheme, it is possible to adjust the immunity of each media, or group of medias, independently.

Two different error correction algorithms are used. The outer code is a Reed Solomon algorithm, $RS(204, 188)$, which for every transport stream packet of length 188 bytes, adds 16 bytes of redundancy capable of correcting up to 8 bytes. The inner code is a convolutional code with the following possible rates: $\frac{1}{2}, \frac{2}{3}, \frac{3}{4}, \frac{5}{6}, \frac{7}{8}$. One rate has to be defined for each hierarchical layer, but they can be different for different layers. Thus, each layer can have its own trade off between useful bit rate and error immunity.

Different modulation schemes can be assigned for different layers. The ones defined in ISDB-T are DQPSK and QPSK, where each carrier transmits two bits per symbol; and also 16-QAM and 64-QAM where each carrier transmits 4 and 6 bits per symbol respectively. ISDB-T differs from other standards, such as DVB-T and ATSC, in its capability of transmitting a low definition signal for handheld receivers in the same bandwidth, using the center segment. For this purpose, this segment, named "segment 0", is defined as the layer A, with very robust transmission parameters. The other 12 segments are used for the layers B, or B and C, depending on the broadcaster's needs. Handheld receivers, also named *one_seg* receivers, tune and demodulate this information. In this case, layer A is usually configured to use QPSK modulation. Unlike the *one_seg* receivers, those able to tune and demodulate the full $6MHz$ channel are named *full_seg*.

The ISDB-T transmission system can be configured to work in three different modes. These modes, keeping the total bit rate constant, increase (mode 3) or decrease (mode 1) the total number or carriers per segment and thus increase (mode 3) or decrease (mode 1) each OFDM symbol length. Particularly, modes 1, 2 and 3 use 108, 216 and 432 carriers per segment, with effective symbol lengths of $252\mu s$, $504\mu s$, and $1004\mu s$ respectively.

A time interleaving is added to randomize the transmitted symbols in order to strengthen the transmission against burst errors. The time interleaving parameter can be configured to $\{0, 4, 8 \text{ or } 16\}$, $\{0, 2, 4 \text{ or } 8\}$ or $\{0, 1, 2 \text{ or } 4\}$, if the system is configured to work in mode 1, 2 or 3 respectively.

As many OFDM systems, ISDB-T adds a cyclic prefix to every OFDM symbol in order to immunize the radio signal from the intersymbol interference introduced by multipath propagation. A cyclic prefix is a copy of the last part of the OFDM symbol which is prepended to it, making the signal periodic [16]. This cyclic prefix is called "guard interval", and its length is expressed as a fraction of the active symbol's length, T_s. ISDB-T's transmission system offers four possible values: $\frac{1}{4}, \frac{1}{8}, \frac{1}{16}$, and $\frac{1}{32}$. The larger this guard interval is, the greater immunity to multipath fading [17]. However, the useful bit rate will decrease as the total time for each OFDM symbol increases.

In this section we have shown how complex an ISDB-T transmission system is. About source coding, only the compression standard was stated. However, it is well known that MPEG-4 offers many options that contribute with a factor to the cardinality of the theoretical set of tests. If we wanted to test the receivers tuning and demodulation of signals with every possible configuration in the transmitter, such a test battery would imply 960 options, multiplied by the many possible combinations of hierarchical layers. We also have 63 possible channels where to test reception (from 07 to 13 in VHF and from 14 to 69 in UHF).

The first -and justified- conclusion we came to during this investigation is that the exhaustive test of all possibilities was not feasible within practical times. We needed to define a strategy able to test a representative subset of configuration parameters which would guarantee the correct reception of digital terrestrial television in every approved receiver.

It should be noted that the set of tests is not a full Cartesian product of all possible combinations, because independent functional blocks, whose failure is also independent, can be identified. This issue will be explained with more detail in that follows.

B. How to test: defined strategy

The defined set of tests was intended only for *full_seg* receivers, particularly to Set-Top Boxes (STB) and digital television sets; however, it could be easily scalable to other types of receivers. A STB is a digital converter that among other features receives the digital signal and converts it to analogical so that it can be seen in an analogical television. There are some features that any STB must have and digital TV sets do not; such is the case of video and audio output interfaces. Therefore, each test was classified according to its target: STB, digital television or both. Tests were also divided into six groups: *hardware*, *video*, *audio*, *reception*, *functionalities* and *documentation*. Each one includes different requirements in some way independent from the others.

The *hardware* group clusters all the interfaces and connectors requirements such as antenna input, composite video output and stereo audio output. Every connector is expected to have its own identifying name at the bottom, or in the users manual. Most of these tests were thought to be done by visual inspection; generally, the technicians in charge only have to certify the presence of the interfaces but not put them to work. It is noteworthy that in [14] the HDMI output and the remote control implementation are not mandatory. Nevertheless, in the protocol both are expected to be present.

The *video* group was intended to test all video source coding configurations expected to be used by local broadcasters. Although [14] establishes that receivers must be able to decode progressive and interlaced signals, with 25, 30/1.001, 50 and 60/1.001 frames per second, in different resolutions and aspect ratios (AR), only three different configurations were included, all of them using the MPEG-4 standard, part 10: AVC/H.264, High Profile @ Level 4.0:

- 576i (720x576, AR: 4:3) @ 50 Hz
- 576i (720x576i, AR: 16:9) @ 50 Hz
- 1080i (1920x1080i, AR: 16:9) @ 50 Hz

This is because Uruguayan analogical TV standard is PAL-N, which has a resolution of 720×576 pixels presented in an interlaced way, at 50 frames per second. DINATEL organized a meeting with local bradcasters, who claimed they will only use the configurations mentioned above.

The *audio* group was also intended to test the audio source coding configurations expected to be used by local broadcasters. Although [14] establishes receivers must be able to decode sampling rates of $32, 44.1$ and 48 KHz and quantizations of 16 and 20 bits, all of them in mono, stereo and multichannel stereo audio modes; only three different configurations were included, in every case using LATM/LOAS for multiplexing and transmission:

- Profile AAC-LC, Estereo (2/0), Sample Rate 48kHz, Quantization 16 bits.
- Profile HE-AAC, Estereo (2/0), Sample Rate 48kHz, Quantization 16 bits.
- Profile HE-AAC, Multichannel Stereo (3/2 + LFE), Sample Rate 48kHz, Quantization 16 bits

The strategy used to prune these tests was the same as for the *video* group.

Regarding the *reception* cluster, there were five important features to be tested: immunity to frequency deviations up to 30 kHz, resilience to clock deviations up to 20 ppm, sensitivity, selectivity and proper reception in every possible configuration of the transmitter. The immunity to frequency deviations can be tested with the current equipment of a Uruguayan test laboratory, at Laboratorio Tecnológico del Uruguay (LATU), but the resilience to clock deviations cannot; it is expected to implement the associated test in the future.

The sensitivity for every receiver is expected to be at least -77 dBm. This is not an arbitrary value: in Uruguay the coverage area for every digital TV broadcasting station is defined to be $51 dB\mu V/m$ [18] and there is a close relationship between these two values. Indeed, the electrical field strength (E) in $dB\mu V/m$ and the power in the receiver's terminals in dBm (P) are related by [19]

$$\begin{aligned} P[dBm] = E[dB\mu V/m] + 20 \log \left(\tfrac{\lambda}{\pi\sqrt{480}} \right) \\ + G[dBi] - 90dB \end{aligned} \tag{1}$$

where G is the antenna gain in dBi and λ is the wavelength of the carrier. Now, if we suppose $\lambda \approx 0.5m$, $G \approx 9dBi$ and a power loss of approximately $4dB$ in cables and connectors, we have that

$$P \approx -77 \ [dBm] \tag{2}$$

Hence, a sensitivity of at least -77 dBm is implicitly supposed when planning digital TV coverage. Therefore, sensitivity is an important parameter to be tested.

The tested selectivity values are just those specified between digital television channels. That is because in Uruguay analogical TV is limited to the VHF band and digital TV is limited to UHF band.

As was mentioned above, testing if the receiver is able to tune and demodulate every possible configuration in the transmitter would lead us to define over a thousand tests. However, it is to be noted that convolutional coding, mapping, time interleaving and the insertion of the cyclic prefix are done in different and independent blocks. So then, for every transmission mode, each possible value must be tested just once. We concluded that the resulting number of configurations to define was 16, including those that broadcasters claimed they will use.

The *functionalities* group gathers a variety of features such as: the possibility of configuring the receiver to Spanish, the ability to perform an automatic channel tuning in the UHF band (channels 14 to 69), virtual channel support and the ability to recognize and reproduce by default the primary audio stream. Unlike the specifications established in [14], Uruguay requests the sequential channel selection through all logical channels (every service) instead of sequential channel selection trough primary services.

Finally, the *documentation* group purpose is to require a Spanish-written user manual that meets at least the following topics: technical information, installation guide, user manual and service contact support. Although [14] does not require its mandatory inclusion, this decision was based on [15].

III. Interactivity

The interactivity aspects of the ISDB-Tb standard are implemented on the Ginga middleware, a complex piece of software that interprets applications written in NCL[1] and that can be extended to run code written in other languages. Ginga-J is a Ginga subsystem or extension, especially promoted by the Brazilian broadcasters, that allows Ginga to run java coded applications.

As a part of the homologation protocol, the plan was to design a set of tests to check that the Ginga implementation provided by the tested device would behave as it is specified in the standard. For this task, we counted with the specification given by the standard and two main sources of tests already developed: one vast and very specific set of tests hosted by the Ginga.org Brazilian-based organization and another, much smaller but more application-oriented, developed by the Argentinian Laboratorio de Investigación y Formación en Informática Avanzada (LIFIA) [9].

Since the Ginga framework was initially developed by Telemidia Lab at the Pontifícia Universidade Católica do Rio de Janeiro (PUC) [8] the first Ginga implementation was made by PUC as a reference for the following, commercial, implementations. As such, this piece of software implemented the most relevant or demonstrative parts of the standard to serve as a guide but was not intended to be deployed inside ISDB-Tb devices. Some industrial vendors, such as Samsung, just implemented the specification given by the standard from scratch, and other such as TQTVD (TOTVS), MOPA and FUCAPI, started from PUC's implementation but all of them included the Ginga-J subsystem too, with the purpose of deploying it in their

[1]NCL is an XML application language that provides support for specifying spatio-temporal synchronization among media objects, media content and presentation alternatives, exhibition on multiple devices, and live producing of interactive non-linear programs.

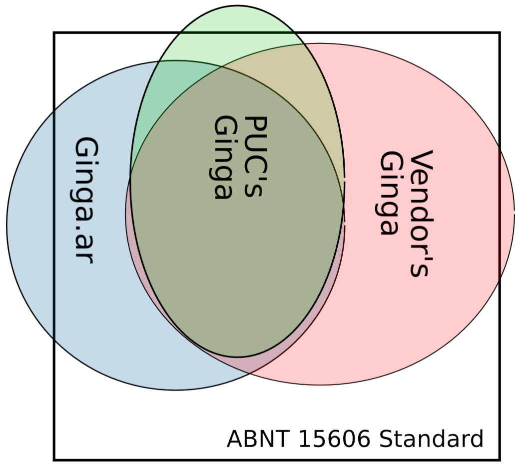

Fig. 1. Different Ginga Implementations Developed Different Features.

TV sets (including TV sets from Sony, SEMP-Toshiba, AOC and PANASONIC) and in Nokia and Motorola cellphones. In the case of the Argentinian LIFIA, they were working with a different perspective: the Argentinian government had decided to distribute low-cost ISDB-Tb set-top boxes and they needed a working Ginga implementation for them. In this context, the LIFIA decided to work on top of PUC's Ginga, just with the Ginga-NCL part leaving the Java code out of their scope. They named it Ginga.ar.

In this context, the Uruguayan government decided to design a homologation procedure to deal with a market with Brazilian-made[2] TV sets and Argentinian-made STBs and, probably, cellphones of unexpected origin and components. To simplify this task, DINATEL decided to leave the Ginga-J extension as an optional feature in the homologation process.

A. Problems Found

The scenario described above leaded us to design an initial protocol based on a selection of the Ginga.org test suite, which has over 500 very specific test cases. However, during the experimentation phase of the work, we realized that the Argentinian and the Brazilian implementations diverge both, one of each other and from the standard's specification. This is reflected in several ways: some methods behave different than it is said in the specification, some methods have different signatures, some features required by the standard are not implemented or, the middleware implements features that are not specified by the standard. Figure 1 tries to depict this problem feature-coverage problem: PUC's reference implementation leaves several features, or variations of features without implementation, industry's implementations are more comprehensive but differ between them, and Ginga.ar which, as it is a work in progress, has different versions with different coverage of the specified features.

This more or less surprising situation leaded us to explore two work directions: (1) to identify, for every Ginga

[2]There are TV sets being imported from other origins such as Mexico or China but they also use one of the Brasilian-based Ginga developments

implementation, the coverage of the standard, and (2) to find interoperable functionalities among every implementation which would enable software developers to produce interesting interactive applications, i.e, the common subset of useful capabilities. As a first approximation we considered two representative implementations (one Argentinian and other Brazilian), performing the following activities: study the existing test suites, evaluate them by the analysis and execution of a subset of the tests on the receivers, and generate corrected versions of the tests. In general, corrections were needed for tests, that are poorly specified, and/or lag behind the latest standard versions. More than 250 tests were executed for more than 15 different configurations, showing an important degree of inconsistency among the tested implementations. For instance, from the 66 ABNT compliance tests for one of the implementations, we found that 21 of them fall out of the standard due to a set of uncompliant individual features, that have a relevant impact on the application design.

B. Defined strategy

An undesired consequence of the incompatibilities described above was that, for the time that they were discovered, it was too late to have a meaningful test suite ready inside the pre-defined legal timeframe. Therefore, it was decided to leave the interactivity aspects of the standard temporally out of the homologation protocol.

With this reality in mind, we decided to use the knowledge gained during this work to assist application developers (governmental and non-governmental organizations, as well as private content providers). They will have to work in a more diverse market with receivers with different interaction capabilities; some of them may decide to produce applications to reach as many users as possible (typically governmental agencies) and others may prefer to focus their efforts in selected sections of the public (e.g., owners of high-end devices with a considerable purchase power).

As a conclusion of this experience, we show that the ISDB-Tb technology definition, and more specifically, the interactive aspects of the standard, are yet in rapid change. Deployment of terrestrial digital TV is an important investment of the society, and therefore it is mandatory, in order to guarantee a successful experience, to maintain a technological observatory and test laboratories, with a strong support of an expert team which can follow the evolution. Moreover, the local content developers need support to take benefit from the possibilities offered by the interactive aspects of digital TV. In the long term, we envision that new convergence standards such as Hybrid Broadcast Broadband TV will eventually take over; again, expertise and tools are needed to keep track of the upcoming standards.

IV. Current situation: ISDB-Tb Receivers Homologation Protocol

The knowledge and experience gained in this process is reflected in the ISDB-Tb Receivers Homologation Protocol [20] which is currently being used in Uruguay to certify *full_seg* receivers, either TV sets or STB. Other receivers such as handheld or USB dongles are not still included.

The Protocol includes 21 tests regarding signal reception and decoding aspects. It also contains a description of the working environment required to perform the tests, normative references, terms and definitions and finally, annexes specify carefully the configurations required for each test and the transmitter settings in which the receiver is expected to work properly. Each test is classified according to its target, has instructions and expected results. Besides, the presentation order of tests is thought to optimize execution time of the suite.

The current version of the protocol is 3.1, but the test suite will evolve, since the harmonization document may -and should- have updates arising from the ISDB-T International Forum. The standards for interactivity are in especially active development.

So far, interactivity tests are not included as admission requirement, but the group is working in this aspect, in relation with CUTI, in order to develop a testbed for applications.

V. Conclusions

This paper presents an interdisciplinary work that address the task of producing an homologation protocol for ISDB-Tb receivers for the Uruguayan market. The work is divided in two areas: in one side the homologation of electrical, signal reception and decoding aspects of the standard, and in the other side, its interactivity functions.

Regarding signal reception and decoding, the main features to be tested were analyzed and a representative tests set was produced (not a comprehensive one), which aims at guaranteeing a right operation of the receiver. This tests set covers the functions of signal reception, processing, decoding and display and fulfills the requirement of being practically feasible and cost-effective while being able to reasonably ensure the compatibility and performance. This test procedure was adopted by the government and is already in production.

Regarding interactivity, the analysis of the Ginga standard and its existing implementations form Brazil and Argentina leaded us to the conclusion that the differences between the implementations are more than marginal and, additionally, none of them is fully compliant with the standards. In some cases there are different understandings, while in many aspects there are clear deviations from the standard. Our conclusion is that the interactivity aspects of the standard are much less mature than the reception and decoding parts and, therefore, it was decided not to perform interactivity tests in this phase.

The experience gained in this work calls for a critical observation of the standard's evolution. For this task the creation of a technical team conformed by partners from government, industry and academia is proposed. Finally, we believe that further work must take into account hybrid media, which are the foreseeable evolution when broadcasting coexists with social networks.

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