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Development of a proposal for a measurement protocol for the ISDB-Tb standard for Costa Rica

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Abstract

This research defines a primary protocol for measuring DTTB in Costa Rica that is implemented with the adopted standard ISDB-Tb. It was required to determine which parameters were necessary to be monitored according to the needs of the Costa Rican entities, and which was the appropriate height to perform the measurements. As a first approach, it was considered appropriate to monitor at least the signal strength and MER in order to be able to evaluate the performance of a DTT transmission. From the field tests performed, it was observed that there is no correlation between the signal strength and the MER regardless of the different measuring heights, which implies that the effect of the multipath propagation is different at every location and every height. Therefore, it was determined that measuring at heights above the 2 m has no significant improvement in DTT reception in the case of channel 18, but it has significant improvements for channels 30 and 49.

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The development of this project was possible because of the help and support of various persons. First, I want to recognize the help received from Anna Umbert as director of the project. Her support was essential because gave me the opportunity of performing this research abroad in my homeland and provided all the guidance required during the process. Second, I would like to recognize the contribution of Glenn Fallas, Esteban Gonzalez, Alberto Araya and all the colleagues from the Administrative Unit of Spectrum, that contributed with their knowledge and experience to the analytical and practice al development of research. And finally, I want to thank my fiancé Adriana, my family and friends for all the support that they gave me during the past two years and a half until the fulfillment of the master with this project.

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1. Introduction

Since the first apparition of the television in the late 1920's, television broadcasting has been a system that has not stopped evolving. As many other systems it has experienced several evolutions, being one of them the transition from analog to digital broadcasting, which is a process that developed countries performed several years ago and currently is occurring in the developing countries.

The transition to DTTB (Digital Terrestrial Television Broadcasting) is the evolution that enables several improvements on television broadcasting, as the efficient use of the radioelectric spectrum, the enhanced image quality obtained by digital receivers that remove the received interferences and display a clear signal without any distortion like the ones experienced in the analog broadcasting, and also the digitalization of the transport stream allows to send higher quality image and sound signals and even information that can be processed by the tuners that will improve the final user experience.

In this context, this thesis focuses on a situation triggered by the analog shut-down related to the transition to DTTB that will occur in Costa Rica in 2019, which consist in the emerging need to establish a measurement protocol to verify the performance of DTT (Digital Terrestrial Television) service, which is implemented with the ISDB-Tb (Integrated Services Digital Broadcasting-Terrestrial built-in) standard. The protocol requires to consider the parameters established in the ISDB-Tb standard, the ITU recommendations and the digital broadcasting signals measurement best practices. This thesis has been developed in the Administrative Unit of Spectrum of the General Direction of Quality within the Superintendence of Telecommunications (SUTEL) [1] which is the telecommunications regulatory body of Costa Rica, where the author works. In a position of telecommunications engineer. Within the functions performed by the department staff, can be mentioned, manage to complaints for interference and illegal use of the spectrum, to perform coverage and occupation studies, to perform studies for granting licenses over the radioelectric spectrum for the different services, to be updated with trends regarding the use of the radioelectric spectrum, among others.

The main objectives to achieve during this investigation are: to determine the required parameters to be measured, to establish the procedures to measure each parameter and to develop verifications by applying the procedures to the experimental permits for DTT services. The accomplishment of those objectives allows the development of an initial proposal of a measuring protocol for DTTB in Costa Rica.

To achieve that, is necessary to establish the requirements of the SUTEL, MICITT (Ministry of Science, Technology and Telecommunications) [2] and Costa Rican Government in relationship with the DTTB service, by reviewing the different documents that regulates it (laws, National Frequency Allocation Plan, etc), and then determine the parameters that are required to be evaluated according to recommendations developed by different standardization bodies.

This investigation can be divided in two mayor tasks, first the bibliographical research, which will consist in the study of different technical recommendations and related researches, that includes information of which parameters are important for specific scenarios and which procedures must be or could be consider in order to perform an evaluation of the DTTB emissions, also, is necessary to determine which are the requirements of the SUTEL, MICITT and Costa Rican Government in relation with the appraisal of the DTTB service, by reviewing the different documents that regulates it (laws, National Frequency Allocation Plan, etc). And the second, is the experimental research, which will consist in the development of software simulations and field tests that will provide the information necessary to determine the optimal configuration that will be implemented in the protocol in order to satisfy the needs and limitations of the SUTEL.

It is important to mention that the field tests performed were developed in a sample of locations that form part of the total sites that are considered by SUTEL to evaluate the coverage of all the telecommunications services. The sample took into consideration locations that were inside the coverage area of the channels that were going to be measured. The measurements were performed for one month, between the 8th of January and the 7th of February. It took about 13 days of measurements, in which between 3 to 6 locations were measured, depending of the closeness between sites.

Once all the data was obtained, it was required to perform a statistical analysis for the different variables that were monitored during the measurements in the different locations, with the purpose of trying to describe the behavior of each variable and the behavior between them, in order to evaluate if all the monitored variables are independent and each of them provide valuable information of the DTTB system. Another expected goal from the statistical analysis was to pursue a simplification of the procedures that will be defined for performing measurements of DTTB, derived from the information provided by the processed data.

The protocol proposal developed during this research will be considered as a first approach to attend the need to establish a measuring procedure for the DTTB by means of ISDB-Tb standard that will be fully deployed in Costa Rica since august 2019. But the scenarios after the analog switchoff will be significantly different than the ones experienced during this research, this is because most of the broadcasters were employing their experimental license for operating with a single transmitter instead of an SFN (Single Frequency Network) as it will be in the future, therefore, it would be reasonable to perform a similar investigation or to develop a new procedure with the improvements necessary to achieve better results that will provide more information of the behavior of DTT networks in Costa Rica.

This thesis consists of 5 chapters, including this first introductory chapter, which also includes the detail of the thesis' objectives and the considerations necessary for the development of the research. The second chapter explains the context in which the investigation is carried out by reviewing the advance of DTTB in Costa Rica and the world, the difference between standards and the characteristics of ISDB-Tb. The third chapter briefly explains the methodology followed to perform the investigation. The fourth chapter details the development of the research and presents the achieved results. And finally, the fifth chapter presents the conclusions of the project and the recommendations for future investigations.

2. State of the art of the technology used or applied in this thesis

In this section, it is shown the context in which the project is developed. First, it is necessary to characterize the actual state of the transition from analog to digital television broadcasting in Costa Rica. Second, it will be explained the designated standard for digital television broadcasting in Costa Rica, ISDB-Tb, which represents the basis for this investigation, and finally, present a summary of the situation of other countries that have finished the implementation of DTT by means of ISDB-Tb standard.

2.1. History of TV broadcasting

As many other inventions, the television has not stopped evolving since its invention. Since the late 1920's were the first experimental forms of the television appeared its evolution has not stopped, but it was until after the World War II were the TV broadcasting became available for the population in a black and white format, with the first deployments developed in United States and Great Britain.

Since the appearance of the black and white TV broadcasting, the technology has suffered some improvements, first was the color TV broadcasting and then was the arrival of the digital television as the latest big evolution in TV broadcasting.

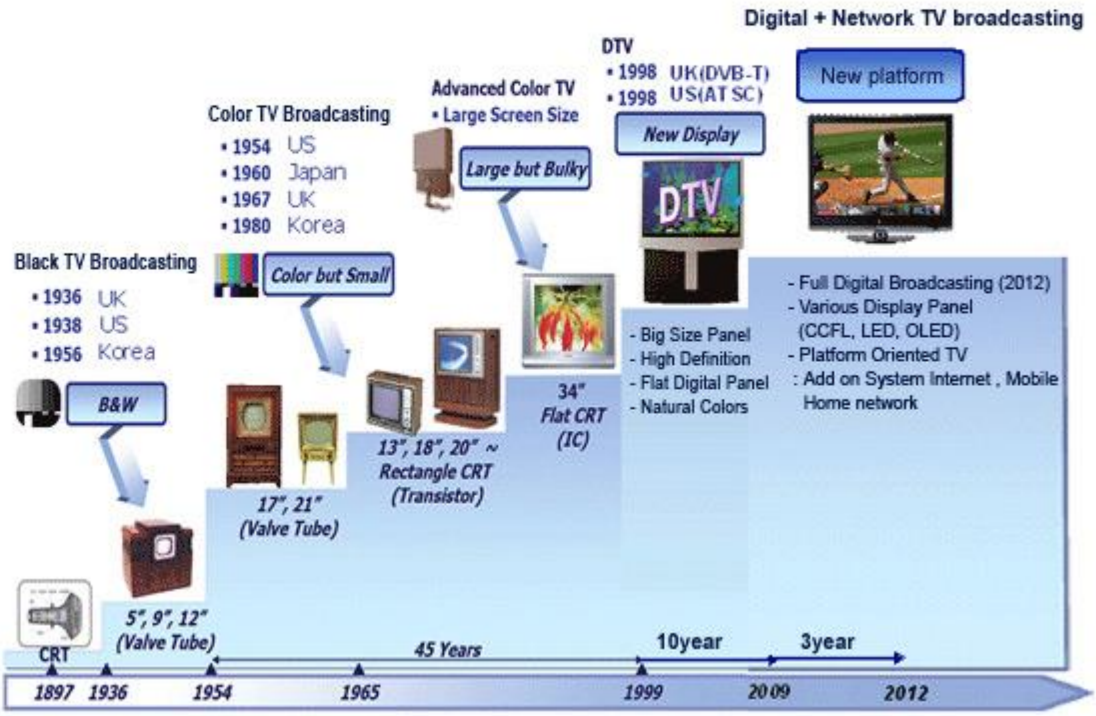

Figure 1. Evolution of television broadcasting. [3]

The advantages that the digital TV broadcasting supply to system are that it makes a more efficient use of the radioelectric spectrum, the digital tuners remove the received interferences and display a clear signal without any distortion like the ones experienced in the analog broadcasting, and also the digitalization of the transport stream allows to send higher quality image and sound signals and even information that can be processed by the tuners that will improve the final user experience.

2.2. Integrated Services Digital Broadcasting-Terrestrial international

There are several organizations in the world that were interested in the developing of digital TV broadcasting, situation that converged in the creation of different standards that are implemented in different parts of the world, the most common are:

- Digital Video Broadcasting (DVB)
- Advanced Television System Committee (ATSC)
- Integrated Services Digital Broadcasting (ISDB)
- Digital Terrestrial Multimedia Broadcasting (DTMB)
- Digital Multimedia Broadcasting (DMB)

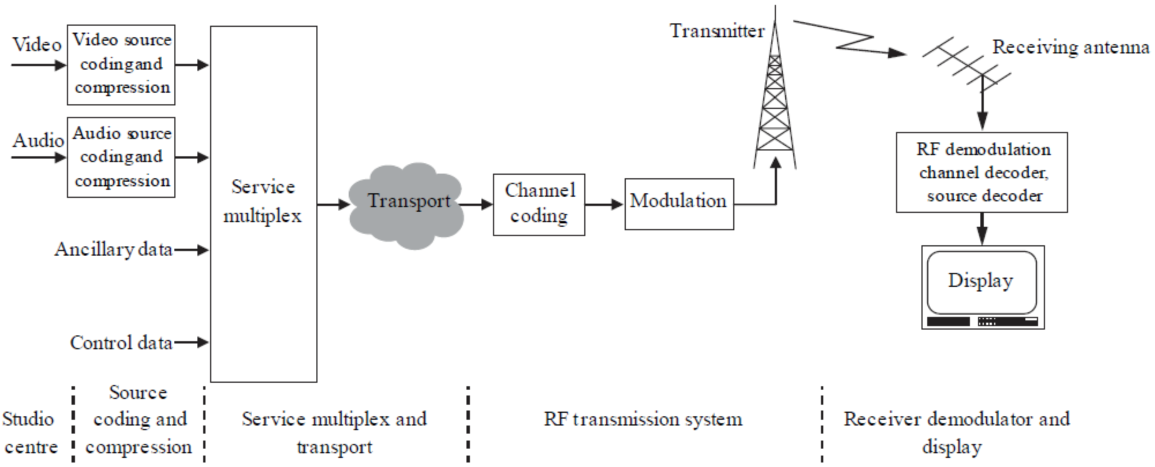

Figure 2. DTV system model. [4]

The three standards that have been adopted in most countries according to Digital Broadcating Expert Group (DiBEG) [5] are ATSC, DVB and ISDB, DTMB has been adopted only by China and DMB was only developed for mobile devices. For this reason, a brief description will be developed to help understand the starting version of those three standards. In the Figure 2 can be observed the typical model of the of a DTTB system, general structure on which the standards mentioned above are based.

2.2.1. The ATSC system

The ATSC Digital Television Standard was developed by the Advanced Television Systems Committee in the USA. According to Wu, Pliszka, Caron, Bouchard and Chouinard [6], this system was designed to transmit HDTV and additional data over a single 6 MHz channel, and is was developed for terrestrial broadcasting and for cable distribution. It is capable of delivering 19.4 Mbit/s of data throughput in a 6 MHz terrestrial channel and 38.8 Mbit/s in a 6 MHz cable television channel. There are two modes of operations available: the 8-VSB "simulcast terrestrial mode" which was designed to be resistant to the interference from the analog service (NTSC), and the 16-VSB "high data rate mode" which was designed to be principally used in cable channels, which present a less noisy scenario in comparison to terrestrial. The input signal to an ATSC modulator is a transport stream with MPEG-2 coded video and Dolby AC-3 coded audio information. Although the system was developed and tested with 6 MHz channels, but the standard can be also implemented in channel bandwidths of 7 or 8 MHz, which implies an increase in the data capacity related to each bandwidth.

In the scenario of terrestrial broadcasting, the standard considered the simultaneous operation of the analog and the digital service, so the system was able to allocate a digital transmitter in the same location of an existing NTSC transmitter and obtain a similar coverage for both services, also generating minimum interference to the existing NTSC service in terms of coverage. This capability is met and even exceeded when the RF transmission characteristics of the system are carefully chosen so the ATSC transmission can coexist with an NTSC environment.

The standard specifies different picture qualities that can be achieved with 18 video formats (SD or HD, progressive or interlaced, and different frame rates). It is considered that the standard has a great potential for implementing data-based services by taking advantage of the opportunistic data transmission capability of the system.

The system is quite efficient and capable of operating under different conditions, perform reception with roof-top or portable antennae. It is designed to withstand many types of interference: existing analog NTSC TV services, white noise, impulse noise, phase noise, continuous wave and passive reflections (multipath). The system is also designed to offer spectrum efficiency and ease of frequency planning, operates using a single carrier modulation scheme, 8-VSB modulation, and it is designed for single transmitter implementation (MFN). However, it is limited on-channel repeater and gap-filler operation are possible.

2.2.2. The DVB-T system

The DVB standards were developed by a European consortium of public and private sector organizations that created the Digital Video Broadcasting Project, in which established the specifications of a standard for terrestrial (DVB-T), satellite (DVB-S) and cable (DVB-C) operations. According to Wu, Pliszka, Caron, Bouchard and Chouinard [6], this family allows the distribution of digital video and digital audio as well as transport of approaching multimedia services. In relation to the encoding process, all the DVB standards use an MPEG-2 coding for video and audio and an MPEG-2 type of multiplexing.

For the case of DVB-T, the system was designed to operate inside the existing UHF spectrum that is allocated for the PAL and SECAM analogue television transmissions. Although the system was originally developed for 8 MHz channels, its use can be extended to any channel bandwidth (7 or 6 MHz) with the corresponding scaling in the data capacity, for the scenario of a 8 MHz channel, the bit rate ranges between 4.98-31.67 Mbit/s and it will depend on the chosen configuration of channel coding parameters, modulation types, and guard interval duration.

The system is capable to adapt not only to Gaussian channels, but also with Ricean and Rayleigh channels, because it was designed with built-in flexibility. It is also capable to resist high-level long delay static and dynamic multipath distortion. DVB-T is characterized by the robustness to interference from delayed signals, either echoes resulting from terrain or building reflections, or signals from distant transmitters in an SFN arrangement.

The system features several selectable parameters that contemplate a large range of carrier-to-noise ratios and channel behaviors; therefore, it supports the reception modes of fixed, portable, or mobile reception, which result in different usable bit rates for each mode. The variety of parameters provide the broadcasters several configurations to implement an operation mode that is adequate for the desired application. For a scenario in which a moderately robust mode is desired, this implies that a lower data rate is required to guarantee a reliable portable reception with a simple set-top antenna. A mode with a higher data rate but reduced robustness could be used in areas where the service planning contemplated the use of frequency-interleaved channels. And a mode with the highest data rate and the lowest robustness can be implemented for the fixed reception scenario where a clear channel is available for DTTB.

The system operates by means of OFDM and has two operational modes. First the “2k mode” which uses a 2k FFT that is suitable for single transmitter operation and for small SFN networks with limited distance between transmitters, and second, a “8k mode” which requires an 8k FFT that can be used for both single transmitter operation and for small and large SFN networks. The system allows the selection between different levels of QAM modulation and different inner code rates and also recognizes a two-level hierarchical channel coding and modulation. Additionally, a guard interval with selectable width separates the transmitted symbols, which allows the system to support different network configurations, such as large area SFN’s and single transmitter operation. These principles are replicated in order to develop the ISDB-T standard.

2.2.3. The ISDB-T system

ISDB standards were developed by the Association of Radio Industries and Businesses (ARIB) in Japan. According to Wu, Pliszka, Caron, Bouchard and Chouinard [6] it consist in a type of broadcasting which integrates systematically various kinds of digital contents including audio, video and multimedia services, of which may combine multi-program video from LDTV to HDTV, multi-program audio, graphics, text, etc. The system was developed for terrestrial (ISDB-T), cable (ISDB-C) and satellite (ISDB-S) broadcasting.

Since ISDB was conceptualized to cover several different types of scenarios, the system must meet a wide range of requirements that may differ from one service to another, in the case of HDTV service a large transmission capacity is required, while some data services require a high service availability as downloading of software, providing a code for a conditional access, and many others. In order to achieve different service requirements, the standard provides several modulation and error protection schemes that can be selected and combined flexibly at the transmission to fulfil the requirements of each service.

For terrestrial broadcasting, the system has been designed to be capable of delivering digital television, sound programs and offer multimedia services in which several kinds of digital data such as video, audio, text and software will be integrated. It also has the objective of providing stable reception through compact, light and inexpensive mobile receivers in addition to integrated receivers typically used in homes.

The modulation method used in ISDB is named as Band Segmented Transmission (BST) OFDM, which consists of a set of common basic frequency blocks called BST Segments, which is an improvement of the COFDM (Coded Orthogonal Frequency Division Multiplexing) by allowing a hierarchical modulation in which some carriers may be modulated differently from others within the same multiplex. Each segment has a bandwidth of $1/14^{th}$ of the terrestrial television channel spacing, depending on the region could be 6, 7, or 8 MHz. In the case of a 6 MHz channel, each of the segments occupies 6/14 MHz = 428.6 kHz of spectrum, as shown in Figure 3.

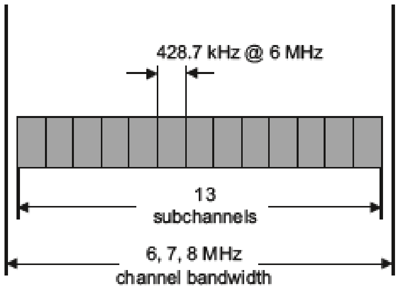

Figure 3. OFDM segments in ISDB-T channels. [7]

The main advantage of BST-OFDM is that allows to perform a hierarchical transmission, which means that different carrier modulation schemes and coding rates of the inner code can be applied to different BST-segments. Each data segment is independent, so it can have its own error protection scheme with a specific coding rate for the inner code, a specific depth of the time interleaving, and can have a different type of modulation scheme between QPSK, DQPSK, 16-QAM or 64 QAM. Therefore, each segment can be configured to satisfy specific service requirements, the combination of several segments allows to reach high data capacities that can support wideband services like HDTV. By transmitting OFDM segment groups with specific transmission parameters, hierarchical transmission is achieved as described in Figure 4. Each terrestrial channel can allocate up to three service layers, which means that a partial reception scenario can be achieved with a narrow-band receiver that can obtain the services contained in a single layer of the transmission channel with bandwidth as low as one OFDM segment.

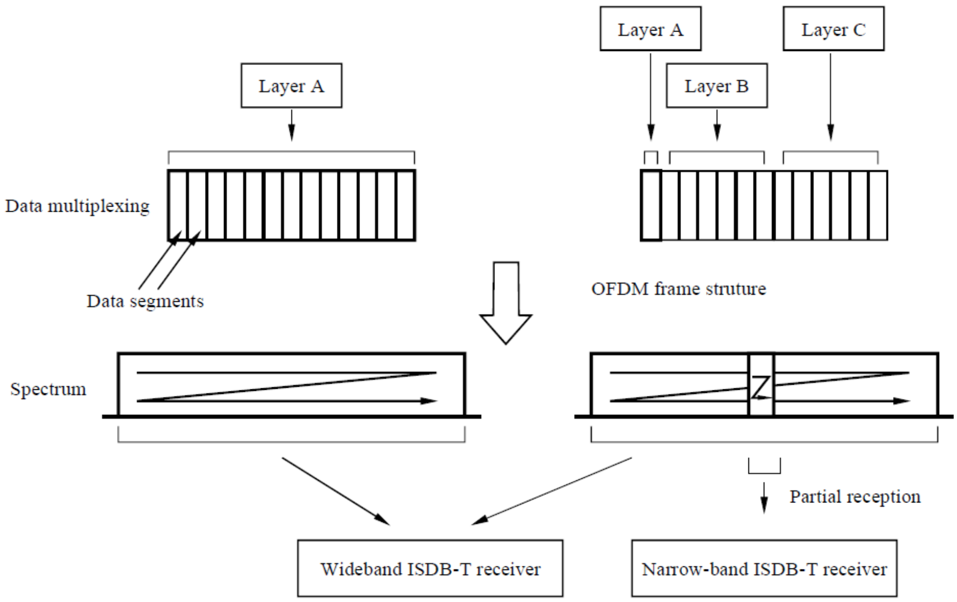

Figure 4. Diagram of hierarchical transmission and partial reception. [8]

Each terrestrial television channel has thirteen active OFDM spectrum segments which corresponds a useful bandwidth of 5.57 MHz for a 6 MHz channel, 6.50 MHz for a 7 MHz channel, and 7.43 MHz for an 8 MHz channel. The system was developed and tested with 6 MHz channels, but it can be scaled to other channel bandwidths with its corresponding variations in the data capacity. A segment of 428.6 kHz in a 6 MHz channel has a net bit rate that ranges between 280.85-1787.28 kbps, therefore, the achievable data throughput for a 5.57 MHz channel ranges between 3.65-23.23 Mbps.

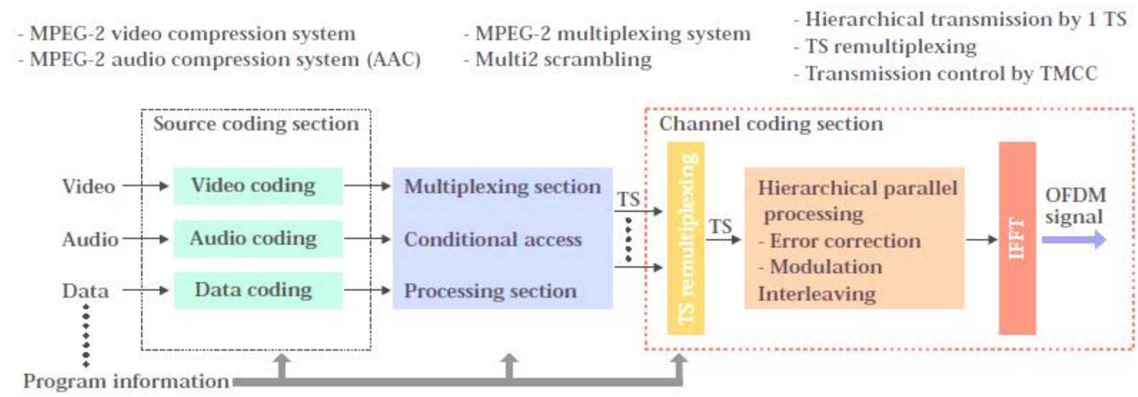

Figure 5. ISDB-T system configuration. [9]

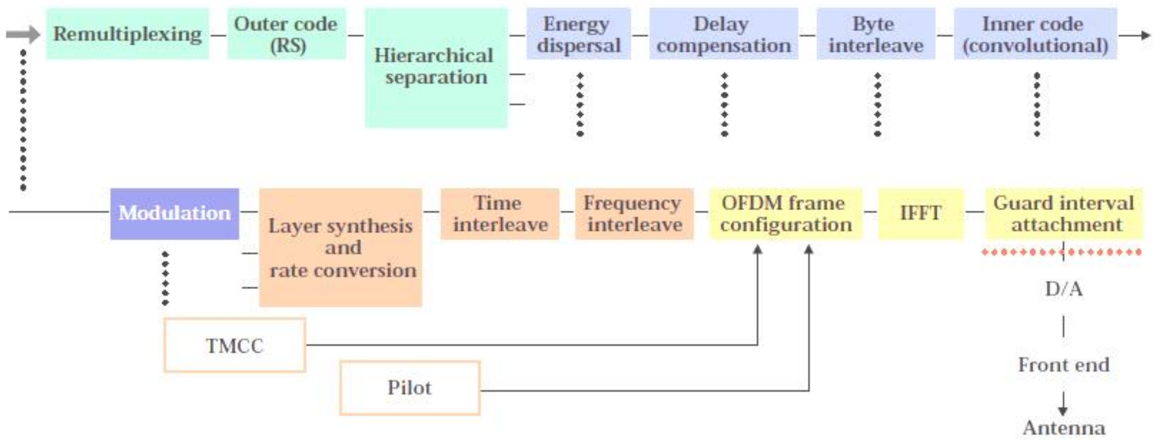

Figure 6. Configuration of channel coding section. [9]

Between all the mentioned standards, ISDB-T is the more flexible and also the more robust standard for some applications standard, because of the possibility of long time interleaving. As DVB-T, ISDB-T has different guard intervals for the separation between transmitted symbols that allows the system to support different network configurations, such as large area SFN's and single transmitter operation, been SFN the more supported and attractive mode. In Table 1 can be observed the different parameters that can be configured for an ISDB-T system.

Transmission Parameter	Mode 1	Mode 2	Mode 3
Number of OFDM segments	13		
Bandwidth	5.575 MHz	5.573 MHz	5.572 MHz
Carrier Interval	3.968 kHz	1.984 kHz	0.992 kHz
Number of carriers	QPSK, 16QAM, 64QAM, DPSK		
Modulation System	252 µs	504 µs	1.008 ms
Effective symbol length	1/4, 1/8, 1/16, 1/32 of effective symbol length		
Number of symbols per frame	204		
Time interleave	4 maximum values: 0, about 0.13, 0.25, 0.5 sec		
Frequency interleave	Intra-segment or inter-segment interleaving		
Inner code	Convolutional coding (1/2, 2/3, 3/4, 5/6, 7/8)		
Outer code	Reed-Solomon (204, 188)		
Information bit rate	3.65 Mbps – 23.23 Mbps		
Hierarchical transmission	Maximum 3 levels		

Table 1. Basic transmission parameters for ISDB-T. [9]

In relation to the encoding process, ISDB-T is just as open as any other standard. In the case of Japan, as it can be observed in Figure 5, MPEG-2 video is used for baseband coding (SDTV and HDTV) and MPEG-2 AAC for audio. Outside of Japan, Brazil is the first country that has decided to adopt ISDB-T, the difference is that Brazil has adopted MPEG-4 AVC as baseband coding for video and for audio MPEG-4 LC AAC or MPEG-4 HE AAC. The Brazilian terrestrial digital TV standard is called SBTVD (Brazilian System of Digital Television from Portuguese Sistema Brasileiro de Televisão Digital) and has been recognized around the world as ISDB-Tb or the international version of ISDB-T.

2.3. DTT in Costa Rica

Nowadays, Costa Rica is in the final stage of the process of transition from analog television broadcast to the digital television broadcast, the date established by Costa Rica's Government by means of the Ministry of Science, Technology and Telecommunications (MICITT) for the analog switchoff is August 14^{th} of 2019, date settled in the article 8 of the "Regulation for the Transition to the Digital Television in Costa Rica", officialized by Executive Decree Nº 36774-MINAET [10].

It is important to mention that the original date established for the analog switchoff was settled for December 15^{th} of 2017, as it was presented in the Executive Decree Nº 36774-MINAET of December 6^{th} of 2011 where was published the first version of the "Regulation for the Transition to the Digital Television in Costa Rica", which later was modified by Executive Decree Nº 40812 of December 5^{th} of 2017, due to the request of the TV broadcasters that declared that the economical investment they have to do is quite considerable and they will need more time to organize their transition.

As mentioned before, on December 6th of 2011 was published the "Regulation for the Transition to the Digital Television in Costa Rica" which settled the beginning and the conditions of the transition period until the analog switchoff. This document indicates the objectives of the migration to DTTB and requirements for the TV broadcasters to start trials of DTV using the standard ISDB-Tb, standard that was established by Executive Decree Nº 36009 MP-MINAET.

As part of this transition process, by June of 2018 already existed 16 TV broadcaster that have experimental permit to make trials for their network operating in ISDB-Tb, also, there are efforts been made to inform the population of the advantages of DTV and the requirements in order to be able to use the service, so the community can be prepared for the analog switchoff. Maybe one of the most important efforts that is occurring, with the intention of increase the acceptance of the population towards the DTV, is the development of a project to help provide ISDB-Tb receivers to the lower income households around the country.

Figure 7. Logo of information campaign of MICITT for transition to DTV. [11]

According to the National Plan of Frequency Allocations [12], for the DTTB it has been taken as reference the norm ABNT NBR 15601:2007 from the Brazilian Association of Technical Norms (ABNT), and as result it has been established for the DTT service the following channels at the frequency band of 470 MHz to 698 MHz conformed by channels with a bandwidth of 6 MHz.

Channel	Channel start frequency (MHz)	Channel final frequency (MHz)	Frequency of the central carrier (MHz)
14	470	476	473+1/7
15	476	482	479+1/7
16	482	488	485+1/7
17	488	494	491+1/7
18	494	500	497+1/7
19	500	506	503+1/7
20	506	512	509+1/7
21	512	518	515+1/7
22	518	524	521+1/7
23	524	530	527+1/7
24	530	536	533+1/7
25	536	542	539+1/7
26	542	548	545+1/7
27	548	554	551+1/7
28	554	560	557+1/7
29	560	566	563+1/7
30	566	572	569+1/7
31	572	578	575+1/7
32	578	584	581+1/7
33	584	590	587+1/7
34	590	596	593+1/7
35	596	602	599+1/7
36	602	608	605+1/7
38	614	620	617+1/7
39	620	626	623+1/7
40	626	632	629+1/7
41	632	638	635+1/7
42	638	644	641+1/7
43	644	650	647+1/7
44	650	656	653+1/7
45	656	662	659+1/7
46	662	668	665+1/7
47	668	674	671+1/7
48	674	680	677+1/7
49	680	686	683+1/7
50	686	692	689+1/7
51	692	698	695+1/7

Table 2. Channeling for DTTB in Costa Rica. [12]

The ABNT NBR 15601 is a technical standard published by the ABNT (Brazilian Association of Technical Standards from Portuguese Associação Brasileira de Normas Técnicas), which is an organization engaged in the preparation of the Brazilian standards, that discuss the aspects related to the transmission over the SBTVD standard. The standard ABNT NBR 15601 details several issues related to characteristics of the transmitters and is fundamental in order to understand its operation and manufacturing. Between the standards developed by ABNT that are addressed to discuss aspects related to the SBTVD standard, it can be mentioned Audio and Video compression (ABNT NBR 15602), Multiplexer and SI (ABNT NBR 15603), Receivers (ABNT NBR 15604), Security (ABNT NBR 15605), Data Coding (ABNT NBR 15606), Interactivity channel (ABNT NBR 15607), Operational guidelines (ABNT NBR 15608), Middleware testing suites (ABNT NBR 15609) and Receivers certification (ABNT NBR 15610).

2.4. ISDB-T around the world

The ISDB-T standard is a widely accepted around the world by several countries according to Digital Broadcating Expert Group (DiBEG) [5], as can be observed in Figure 8, mainly in Central and South America, the most important examples are Japan and Brazil as developers of the standards, ISDB-T and ISDB-Tb respectively. Beside those countries, other countries that have adopted ISDB-T as the standard for DTTB are. Philippines, Maldives and Sri Lank in Asia, Botswana in Africa, Uruguay, Argentina, Chile, Paraguay, Bolivia, Peru, Ecuador and Venezuela in South America and Guatemala, Nicaragua, Honduras, El Salvador and Costa Rica in Central America.

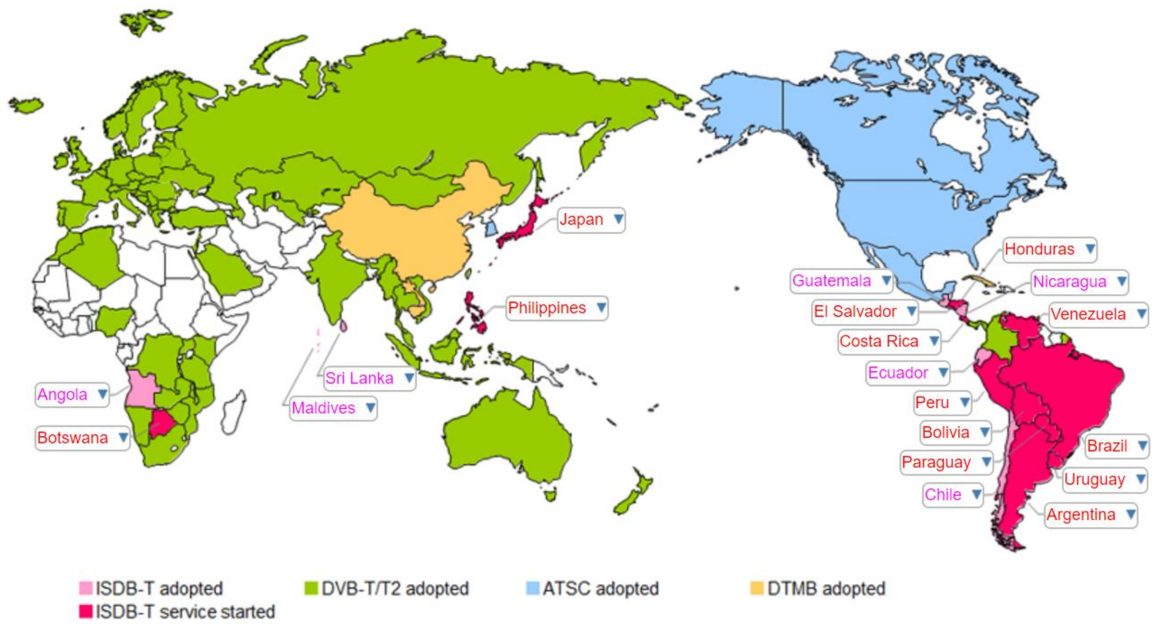

Figure 8. Adopted standards for DTTB by country as of March 2019. [5]

In December of 2003, Japan adopted the ISDB-T standard for the operation of the broadcast television and in July 24th of 2011 it took place the analog switchoff. In the case of Brazil, in June 29th of 2006 announced the selection of ISDB-T based SBTVD (Brazilian System of Digital Television from Portuguese Sistema Brasileiro de Televisão Digital) as the standard for DTTB, which was launched on December of 2007 and was expected to be fully implemented by 2016.

3. Methodology / project development

As mentioned at the beginning of the thesis, the purpose of this work is to contribute with the develop of a measurement protocol for the DTV service implemented by means of ISDB-Tb standard for Costa Rica. To achieve that, is necessary to establish the requirements of the SUTEL, MICITT and Costa Rican Government in relationship with the DTTB service, by reviewing the different documents that regulates it (laws, National Frequency Allocation Plan, etc).

Considering the requirements of this research, the process that will be carried out can be classified as an experimental investigation developed in a field test scenario, and it can be divided in two mayor tasks, first the bibliographical research, which will consist in the study of different technical recommendations and researches, that carry information of which parameters and which procedures must be or could be considered in order to perform an evaluation of the performance of the DTTB service. And the second, is the experimental research, which will consist in the development of software simulations and field tests that will provide the information necessary to determine the optimal configuration that will be implemented in the protocol in order to satisfy the needs and limitations of the SUTEL.

3.1. Bibliographical research

This research will consist in an investigation of different recommendations developed by several standardization bodies that are related with the operation and measurement of DTTB service and some specifics for the ISDB-Tb standard, also will be necessary to study different papers that explain how measurements have been developed in some other countries and researches, and determine which are the considerations they took into account and which are the problems and conclusions they arrived for their specific scenario.

After that study, it is important to determine which of the information obtained has a better suit for the case of Costa Rica and determine also recommendations that can be modified to fit and be carried out without limitations by the SUTEL.

3.2. Experimental research

After developing all the bibliographical research related to the investigation, it starts the practical part of the project in which are going to be employed all the tools available in the institution to help justify all the decisions made in relation to the project. First, it will be necessary to use the software for coverage predictions employed by the SUTEL, which is the Chirplus BC developed by the company LS Telcom [13], to have an initial perspective of the areas that are needed to verify the coverage of the DTTB service.

Second, it is necessary to develop a field verification of the coverage predictions and measurement of parameters to verify the DTTB emissions, this will be performed with the equipment own by the SUTEL from the manufacturer Rhode & Schwarz that are installed in a vehicle, as shown in Figure 9. The main equipment that can be used to monitor the DTTB service is the ETL TV analyzer [14], which is a device that can perform as a conventional spectrum analyzer or as an analog or digital TV analyzer that allows, in the case of the ISDB-Tb, to measure parameters as the BER, MER and observe the modulation constellations.

Finally, after analyzing the measurements performed in the field, it would be necessary to evaluate the procedures performed in order to determine improvements that can be applied to them. This will be the optimal ways to execute the measurements that will be specified in the proposal of the protocol for measurement of ISDB-Tb in Costa Rica.

Figure 9. SUTEL's mobile measuring stations. [15]

3.3. <u>Limitations of the research</u>

Is important to take into consideration the requirements and limitations of the SUTEL in order to develop the procedures to perform the measurements of ISDB-Tb that will conform the desired protocol. Among them it can be mentioned:

- Every year, the SUTEL performs a measurement procedure to verify the spectrum coverage across the country by developing measurements in 212 preselected locations in which the signal level of all the services allocated in the spectrum are verified. Due to the above, it is necessary that the protocol that is going to be proposed can be performed without affecting the existing procedures. The protocol should avoid having a high impact on the measurement execution time because this will alter all the planification of the different tasks for the work team thru the year.
- It is necessary that the proposal considers only the use of equipment that is already available for use of SUTEL, the acquisition of new measuring equipment it is not an option for the institution at this moment, but recommendations for future improvements of the equipment can be presented. In short term, the acquisition of antennas can be considered.
- It is important to take into consideration the scope of the SUTEL as a regulation body, which requires to perform measurements of all the allocated channels in the DTT service in a single measurement run, so the amount of measurements and the procedure to take them needs to be very different from the one performed by the concessionaire in order to verify the proper operation of their network, this is something very important to take into account in the moment of analyzing the different recommendations that can be found, in order to determine if they can really fit to the needs of the SUTEL as a regulation body.

4. Development and achieved results

This section describes the various processes carried out during the development of the project to achieve the integration of the recommendations emitted by specialized agencies, studies developed around the world, field tests analysis and the needs of SUTEL in order to develop a proposal of a protocol to measure ISDB-T in Costa Rica.

4.1. Recommendations by specialized agencies

After a research of several studies in which they performed field tests to evaluate the behavior of DTTB, mostly working in the ISDB-Tb standard, it was identified that mostly all of them used as reference the recommendation Rep. ITU-R BT 2035-2 with the title: "Guidelines and techniques for the evaluation of digital terrestrial television broadcasting systems including assessment of their coverage areas" [16].

This recommendation establishes that the main objective of DTTB testing and trials is to evaluate the performance of the available systems in different transmission configurations and reception conditions, like urban, suburban, and rural conditions, indoor or rooftop reception and reception on portable and mobile receivers.

Between the guidelines specified in the document, they are classified into two different plans: Laboratory Test plans and Field Test plans. Because of the objectives of this research, it is only considered the guidelines for Field Test plans, which are also sub classified into three main modes: Coverage testing, Service testing (receivability) and Capturing channel characteristics.

The recommended practices for test plan implementations for Field testing usually concentrate on particular situations related to the objectives depending upon the immediate requirements of the researcher, in this case SUTEL. Usually measuring procedures developed using the Rep. ITU-R BT 2035-2 have one or more of the following objectives:

- identify the variables in the environment and recommend the minimum set of variables to be measured.
- measure actual "service" versus predicted "coverage".
- to collect data useful in improving the DTTB system performance.
- evaluate the receivability of DTTB systems for a broad range of different receiving modes.

For the case of the SUTEL, the objectives that fit the most to the present needs of the institution is to identify the minimum set of variables to measure and perform a preliminary comparison of the measured service versus the predicted coverage. This as a first approach to obtain a measuring protocol for ISDB-T. In the future, the reach of the protocol can be expanded to fulfil other objectives like evaluating the receivability in different receiving modes and different receiving conditions, but there are some other objectives that are not in the scope of SUTEL measurements, because of the nature of the institution, like obtaining data that is useful to improve the system performance because that is a responsibility of each broadcaster not of the regulator.

As already mentioned, the field tests are classified in Coverage testing, Service testing (receivability) and Capturing channel characteristics, and they are described as the following:

- **Coverage testing**

For the purpose of Rep. ITU-R BT 2035-2, coverage is defined as the determination of actual field strengths measured for a given telecommunication service. There are generally two purposes for coverage measurements: confirm the adequate operation of the telecommunication service and supply additional data for terrain propagation algorithms that can be used to perform spectrum allocation planning and potential interference estimation.

This type of tests are usually carried out using standardized test methods which typically use antennas calibrated to a standard dipole and placed at 9.1 m height above ground, and are often organized in order that the measurements are performed along radials, arcs, grids and clusters. They are used all around the world to perform verifications of coverage, transmission antenna radiation patterns, and providing data for the refinement of the propagation algorithms used for the planning factors for allocating broadcast station spectrum.

- **Service testing (receivability)**

Service or Receivability testing according Rep. ITU-R BT 2035-2 is defined as the process of determining under which different operating conditions the digital television signals can be received and decoded, considering any location where viewers normally use television receivers and the corresponding periods of use. These operating conditions include the use of antennas typically sele2cted for each receiving mode under test.

Typically, service measurements employ DTT receivers designed to operate with recording equipment that acquires the signal level, carrier-to-noise ratio, margin-to-threshold, error rate, antenna orientation criticality and other information. These measurements may not be as easily repeatable as the coverage measurements.

- **Capturing channel characteristics**

Capturing channel characteristics according Rep. ITU-R BT 2035-2, is defined as the process for determining the channel characterization by the detailed measurement of specific signal conditions at particular times and locations by means of specific fixed and movable antennas. The signal characteristics measurements should include the consequences of channel impairments as level variations, impulse noise, in-band interference, and multipaths.

Although this classification helps to understand the different modes available for the DTTB systems evaluation, there are several similarities between the modes that allows to save a lot of time and resources by preparing a test plan which combines several parts of these testing procedures into just one procedure. Is also important to take into account that for any procedure a sample containing a large amount of measurements are necessary to obtain statistically significant results that allow to establish a statistical database from which a level coverage or a level of service can be derived. Also, it can be planned limited tests that can help to achieve specific objectives but will not be used to predict an overall coverage or service level.

It is important to highlight that for the purposes of the SUTEL, the tests that adapt in some way to the established objectives are the Coverage testing and Service testing (receivability), the test of Capturing channel characteristics is a test mode that obtains results that are out of the scope of the institution. Because of that, from this point the research will focus principally on understanding the Coverage testing and Service testing.

According to Rep. ITU-R BT 2035-2, it can be considered five different receiving modes which are fixed, portable, pedestrian, mobile and personal.

- Fixed reception: reception by an immobile receiver and receiver antennas. Typically, this includes a roof-top mounted antenna (outdoor) or a fixed-location indoor antenna.
- Portable reception: reception by a receiver that can be moved from place to place, that uses a self-contained receiving antenna, but that remains stationary during operation.
- Pedestrian reception: reception by a receiver that is moving at no more than 5 km/h. Typically, this is a receiver that may be used while walking, or a hand-held receiver where occasional and frequent short movements occur.
- Mobile reception is defined as reception by a receiver that is moving at greater than 5 km/h. Typically, this is a receiver used in a vehicle moving faster than walking speed.
- Personal reception: reception by a receiver that is moving at lesser or greater than 5 km/h and the receiver uses a low-gain antenna used on hand-held devices. Typically, this is a hand-held receiver that may be used anywhere, including inside a moving vehicle.

Another important topic to clarify is which signal is going to be measured, and there are two options: in-service and out-service measurements. The in-service measurements consist in the use of the DTTB received signal without modifications or could be used a known video sequence with appropriate sound that is transmitted in a loop to enable evaluation of the program stream errors; and in the other hand, the out-of-service measurements consist in the use of signals that are not available for regular viewing, rather they are used specially designed test signals. It is required that these test signals have the same average power and occupy the same spectrum as a DTTB signal but may be designed for specific out-of-service measurements such as channel characterization.

In relation with the antennas proposed for the different tests, it is recommended for coverage measurements, that the antenna must be calibrated with a reference of a standard dipole installed on a mast at the recommended height above ground (9.1 m), they are normally directed towards the transmission tower, in the direction of theorical maximum signal. For other type of tests different than coverage, measurements could be made with the antenna oriented in other directions.

For the cases of service and channel characterization measurements the antenna can be professional or commercial, depends on which suit more according to the objectives of the field test plan. These antennas are typically employed in an “in-service” setting and usually are used just a few meters above the floor and relatively close to people and surrounding objects, they should be installed in a way that allows the testing personnel to easily point, tilt and position the antenna with accuracy in order to document meaningful results from such movements.

Antennas may be oriented to an optimal position where the maximum signal or most easily received signal is detected or non-optimal position where can be sited for receiving signals from multiple directions. It is also recommended, for different classes of services, to perform measurements to identify the criticality of the antenna orientation in relation with the receivers' capability to correctly decode the DTV signal.

According to Rep. ITU-R BT 2035-2, antennas can be operated in different modes for service testing and channel characterization measurements, they are the following:

- Fixed outdoor mode: the measurements should be performed with an antenna at 9.1 m above ground and can operate with an optimal or non-optimal orientation.
- Fixed indoor mode: the measurements are normally performed with a consumer style antenna and it can be used for service or channel characterization measurements. It should be characterized for gain and pattern to a reference of standard dipole and mounted about 1.5 m above the floor and may be used in an optimal or non-optimal orientation according to the field test plan.
- Portable receiving mode: the measurements are normally performed with a consumer style antenna that can be non-directional (monopole) or directional (dipole or multiple element). It must be characterized for gain and pattern to a reference of standard dipole. In this mode, antennas are usually positioned about 1 m above the floor and may be oriented in an optimal or non-optimal position according to the field test plan.
- Pedestrian receiving mode: the measurements are normally performed with an antenna of random directional characteristics with little or no gain. If possible, the antenna should be characterized for gain and pattern to a reference of standard dipole and mounted about 1 m above the floor. Due to the low gain, the orientation of the antennas in pedestrian and personal applications are considered to be non-optimal.
- Mobile receiving mode: the measurements are normally performed with a monopole antenna and mounted in fixed positions on vehicles in a manner to maximize their exposure to radio signals. Mobile antennas must be characterized for gain to a reference of standard dipole and usually are considered to be non-optimal.
- Personal receiving mode: the measurements are normally performed with an antenna of random directional characteristics with little or no gain. If possible, the antenna should be characterized for gain and pattern to a reference of standard dipole and mounted about 1 m above the floor.

Related to the time that should be measured every test, Rep. ITU-R BT 2035-2 recommends different test durations, the duration will be defined by the receiving mode and includes a wide range of options including seasonal (months or years), very long term (days or months), long term (minutes or hours), short term (seconds to minutes) and very short term (seconds to less than a second). Usually, coverage measurements are performed for short periods of time. In the case of fixed position coverage measurements performed over long periods of time (hours, days, months, years), are used to obtain information about the effect of weather, seasons and day-night variations. In the case of service measurements, the test duration is recommended to be 5 minutes minimum. During that time, single (averaged over the period) or multiple measurements may be performed according to the field test plan. On the other hand, for the case of capturing channel characteristics, the test duration is variable, what is necessary is to choose a duration that satisfies the field test plan and also suits the storage capability of the test equipment, usually this means that the measuring time corresponds to short periods of time due to storage capacity of the equipment, being considered a minimum of 20 s of duration.

4.1.1. Coverage measurement procedures

Coverage measurements are based on the field strength measurement of the digitally modulated television signal with an instrument capable of indicating precisely the average amplitude of that signal, these measurements need to be performed in several test sites in order to determine the coverage of a signal. The following is a recommendation for establishment of a procedure to be performed at each selected site. In Figure 10 can be observed a block diagram of the equipment recommended to execute field test measurements according Rep. ITU-R BT 2035-2. Notice that the diagram includes equipment necessary to perform not only coverage measurements but also service measurements and channel characterization.

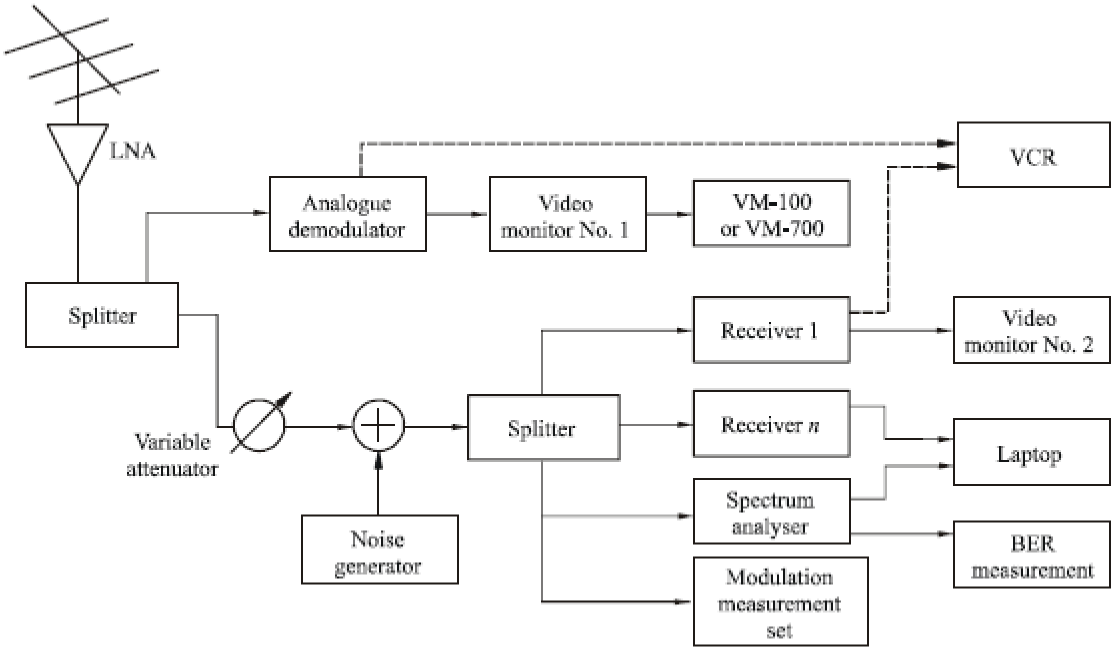

Figure 10. Equipment Set-Up for field tests. [16]

The recommended method to collect valuable data to evaluate each site consist on performing an accurate measurement on the location but also to make additional measurements around the site by the delimitation of a cluster. For Rep. ITU-R BT 2035-2, a cluster is defined as one established initial measurement point and a minimum of four additional measurement points separated by a specified distance from the initial measurement point, as long it is possible, the initial measurement point shall be at the center point respect to the other points.

Is recommended that cluster measurements have a minimum of five evenly distributed measurement points to obtain a complete set of data over an area. In case of requiring measuring several frequencies at one location, the cluster measurement area should be defined as 9 m^2 (3 m per side). In Figure 11 can be observed some recommended patterns according Rep. ITU-R BT 2035-2.

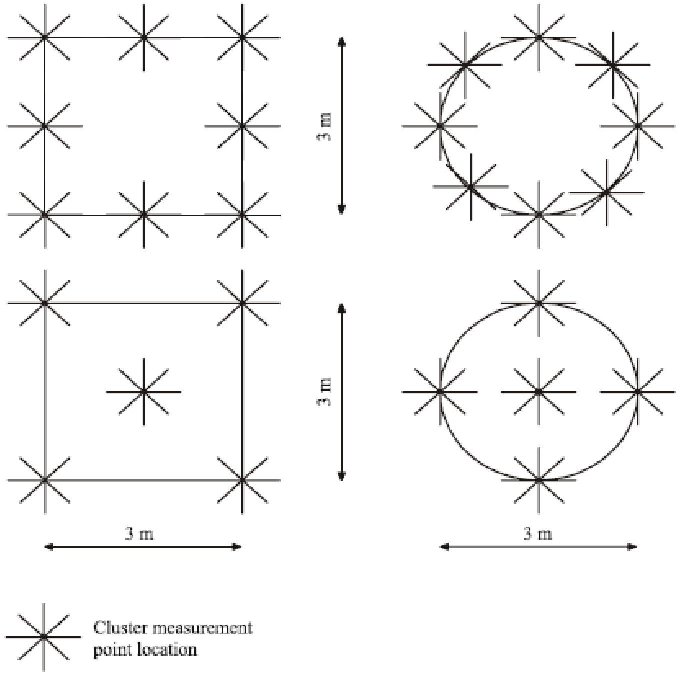

Figure 11. Cluster measurement point arrangements. [16]

Cluster measurements shall be applied when it is identified that a location needs to have a further analysis. In case that overhead obstacles make impossible a cluster measurement, a 30M run may be executed instead of the mobile run. The 30M run is described by positioning the antenna at 9.1 m above ground level and driving the vehicle back and forth over a straight line of 30.5 m towards each direction (total of 61 m). Should be recorded the average field strength and the field value for at least five fixed points within 61 m of the measured route, and if it is possible, the continuous data acquisition along the measuring route is preferable.

Is important to take into consideration that clusters and 30M runs are desirable at locations where the orientation of the receiving antenna towards the strongest signal differs from the orientation towards the transmitter. Under these circumstances, field strength should be measured with the antenna oriented towards the transmitter and then towards the strongest signal.

The equipment that is necessary for the development of a coverage measurement procedure consist mainly of an instrumentation vehicle with telescoping mast that is capable of raising a directable standard reference antenna to a height of 9.1 m above ground level and transporting the elevated antenna a linear distance of 30.5 m in case the 30M run is desirable. According Rep. ITU-R BT 2035-2, the equipment included in the vehicle should be the following:

- Calibrated reference antenna(s), UHF and/or VHF.
- Calibrated antenna balun (if required) and coax impedance matching network.
- Calibrated coaxial RF distribution system which may include a band pass filter, low noise amplifier, RF splitter and optional instrumentation devices.
- Calibrated, average reading RF voltmeter(s) and system components with adequate dynamic range, bandwidth, selectivity and sensitivity to measure DTTB

field strength to predicted noise limited thresholds without introducing instrumentation bias or distortion to the measurement.

- Differentially corrected GPS receiver.
- Spectrum analyzer for "best reception azimuth" antenna orientation indicator and for spectrum display image capture or recording. Some options are desired such as channel power, true RMS power detector and delay profile measurement. Instrument state programming and measured data storage capabilities are other desired options, commonplace in modern equipment. Storage of the received DTTB signal spectrum may be used to ascertain the degree of multipath at each measurement site.
- Digital television receivers.
- Random noise generator.

According Rep. ITU-R BT 2035-2, is expected that the results obtained from the measurement procedure include, but should not be restricted to, the following information:

- Field strength in dBµV/m (minimum, maximum, and median value).
- System margin. Input RF signal shall be attenuated in a controlled manner until TOV is reached.
- Distance and bearing to transmitting antenna location.
- Ground elevation at measuring location (measured or calculated).
- Date, time of day, topography, traffic and weather observations.
- Azimuth orientation of receiving antenna for best reception and for maximum field strength (if different) with vertical angle of mast/antenna support structure.
- A detailed equipment list specifying each antenna, measuring instrument, and system component, its manufacturer, type, serial number, rated accuracy and date of most recent calibration by either its manufacturer or a qualified calibration laboratory.
- A detailed block diagram of the coverage survey system.
- A detailed description of the procedure, date, time, and tabulated data for the pre-test field calibration check of each of the coverage survey system components conducted at the beginning of each measurement cycle.

4.1.2. Service measurement procedures

Service measurements are usually performed in a procedure that simulates the real-world receiving situations. It is important to mention that the measurement procedures may vary according to the receiving mode. When the 30M run is applied, the measurement location selection cannot be at the "best" location. It should be performed at an average location. According Rep. ITU-R BT 2035-2, the considerations necessary for each reception mode are the following:

- Outdoor fixed measurements: follow the same procedure as coverage measurements but neither clusters nor 30 m run are mandatory. Is important to document the criticality of antenna orientation on the receiver capability to correctly decode the received DTTB signals, and to measure the full azimuth range of antenna orientations that result in adequate operation of the DTTB receiver. For statistical confidence, is recommended to measure a minimum of 100 sites.
- Indoor fixed measurements: is recommended to be performed in a minimum of 20% of the receiving sites in which were documented a high signal strength and good

outdoor reception. During the tests is required to simulate scenarios with typical receiving conditions where the movement of nearby persons and the operation of household appliances are controlled. The impact of different variables in the reception should be documented in order to enable the consolidation of data from multiple test plans.

- Portable: usually performed in the same location as fixed indoor measurements. In this test is important to record the site description and antenna pointing criticality. During the tests is required to simulate scenarios with typical receiving conditions where the movement of nearby persons and the operation of household appliances are controlled. The impact of different variables in the reception should be documented in order to enable the consolidation of data from multiple test plans.
- Pedestrian: commonly executed in the surrounding areas of the site used for indoor reception, with a minimum of 20 sites. The receiver should be on a position that recreates real operation situations.
- Mobile: for this type of test is necessary to define a route of at least 10 km, that is usually divided in segments of 1 km long. Each of the segments is described in terms of multipaths, analogue interference, traffic conditions and other obstructions.
- Personal: this type of test is usually performed in the same route used for mobile reception tests and is recommended to use the same antenna for pedestrian reception test.

It is necessary to establish the test duration to adequately capture the desired number of measurements and that this test period represents typical reception conditions, is important that all data taken must be recorded. Also, the test plan should set the duration of "not affected reception" which will be used as the pass/fail criteria which is usually settled in a five-minute period of not affected reception.

Additionally, to the normal test duration, the procedure may also include variable adjustable observation periods depending on the environment to be tested, like the effect of airplane flutter, the effects of trees moving in the wind or the moving traffic variations. In case that service measurements include a tendency towards specific reception factors such as multipath, aircraft flutter or effects of building walls or trees, rather than random, it must be noted as such in the test results and database.

In the case of service measurements, the antenna shall be selected according to the reception mode (fixed, portable, pedestrian, mobile and personal). It is desired that the selected antenna is representative of users' typical receiving antennas. In relation with the rest of equipment necessary for the measurement, the list of test equipment is similar to the detailed list presented for coverage measurements in section 4.1.1, but the difference should be that for modes that require testing indoor and portable receivability the test equipment should be moved to the user's house according to the test procedure.

According Rep. ITU-R BT 2035-2, for the procedure for a service measurement it is required to obtain at least one set of measurements, but more than one can be obtained during a service measurement. Other measurements to enhance or describe a particular reception condition in more detail may be made as desired. It is expected that the results obtained from the measurement procedure should include, but should not be restricted to, the following information:

- Field strength
- Noise floor

- Noise added until TOV is reached
- C/N (to measure the increase of C/N with local impairments compared to laboratory result)
- Calculated margin to threshold
- BER or segment error rate (SER)
- Delay profile
- Equalizer tap values and energy
- Detailed location of antenna
- Antenna description, including its polarization
- Antenna orientation
- Calibration of measurement system
- Site location details (geographical coordinates)
- Time of day
- Description of building in which, or around which measurements are made
- Nature of area immediately surrounding the antenna.

Practical considerations lead to a range of 20 to 100 measuring sites to obtain statistically significant results that reflect the actual performance of the measured DTTB system, but for other reasonable statistical confidence intervals may require significantly more measuring locations. As mentioned above, fixed outdoor measurements usually require a minimum of 100 sites while the other service receivability tests a minimum of 20 sites.

4.1.3. Capture of channel characteristics

The channel characteristics at a location describe the conditions of received signal, besides of indicating parameters like received signal strength and the channel characteristics also describe aspects such as impulse response, and particularly multipath conditions with time variations. The particularities of each location will impact the received signal, its surroundings, objects in the transmission path, interference, noise, and the receiving antenna type, height and orientation.

The received signal usually suffers of multipath propagation, which means that the signal takes several different paths from the transmitter with different arrival times. The main component, usually defined as the strongest of the multipath components, may be the direct path signal from the transmitter to the receiver in a free line of sight scenario, in other cases one of the reflected signals should be the strongest, but this is a situation that will depend of each location.

Usually, the positions of the signals are referenced to the strongest signal, there would be signals arriving earlier called leading (pre-echoes) or after the main signal called lagging (post-echoes). Rarely these echoes are static and usually they change constantly over time in amplitude and/or delay, condition that is called dynamic multipath. If the signals vary in amplitude such that one echo becomes the stronger signal, then the reference for the time offset of the other reflections change. For this case, the variation of the relative amplitudes of the components leave unaffected the distribution of the multipath in time.

In relation to the above, in every scenario the characteristics and orientation of the receiving antenna will affect the degree of received multipath, therefore, it is important to understand the impact of the chosen antenna and its orientation in the measuring of a signal and to document this information for further analysis. According Rep. ITU-R BT 2035-2, the general procedure for this kind of test is to record the RF DTTB signal for a minimum of 20 seconds. The two proposed methodologies to perform channel characteristics methods are the following:

- Direct method: A normal transmitted signal or a special out-of service sequence specific signal is transmitted from the transmission site and recorded at the receiving site for analysis. The captured RF sequence is compared to the actual receiving characteristics for checking of consistency.
- DTTB RF signal method: there are two ways to obtain the channel characteristics in case the direct method is not available, first using the Vestigial-Sideband (VSB) that is a tap inferential method in which the equalizer tap values of a receiver are saved to allow characterization by calculating the multipath, and the second consist of using Coded orthogonal frequency division multiplex (COFDM) based systems that allows to record the delay profile to perform the channel characterization.

In the case of the direct method, the captured signal provides the proper data to perform an analysis that include at least the echo length, phase, and amplitude (channel impulse response) of the channel. Results allow to determine the complexity of the channel degradation and which improvements are needed in order to improve the reception of the measured channel. In the case of DTTB RF signal method, the recorded signals can be fed directly to receivers to evaluate the effects on design improvements or of adjustments on receivers' performance with the signals recorded. The signal can also be fed simultaneously to a number of receivers to compare their performance under exactly the same channel conditions.

4.1.4. Field survey methodology for fixed measurement of digital television reception

This section describes the procedure to capture fixed digital reception characteristics in a common format, such that different organizations could perform measurements and subsequent analysis allowing the comparison of DTTB coverage between studies.

The main goal of this methodology is to confirm DTTB coverage requirements, and the results of this procedure may lead to refinement of predictive algorithms to assist the future planning and better implementation of digital television services.

Is extremely difficult to perform a full coverage verification because of the time and cost constraints, that is the reason only a statistically small number of measurements will be possible, consequently, the objective at the time of selecting the measurement locations should be to identify areas where digital reception may be a problem to allow early identification of problems and solutions to be developed.

The diagram of the proposed measuring system is shown in Figure 12. In relation with the equipment necessary for the test, Rep. ITU-R BT 2035-2 establish that the measurements should be performed with an antenna which technical characteristics for the frequencies to be measured are known, also, the system should have sufficient gain such that the overall gain/loss of the measurement system is as close as possible to a DTTB test receiving system for a rural environment. The minimum equipment required for the test are the following:

- calibrated, adjustable dipole test antenna (VHF or UHF as appropriate);
- measurement antennas for the bands to be measured;
- calibrated test cable;
- signal strength measuring set with spectrum analyzer function;
- digital decoder;
- picture monitor;

- field survey vehicle with 10 m telescopic mast and power supply system.

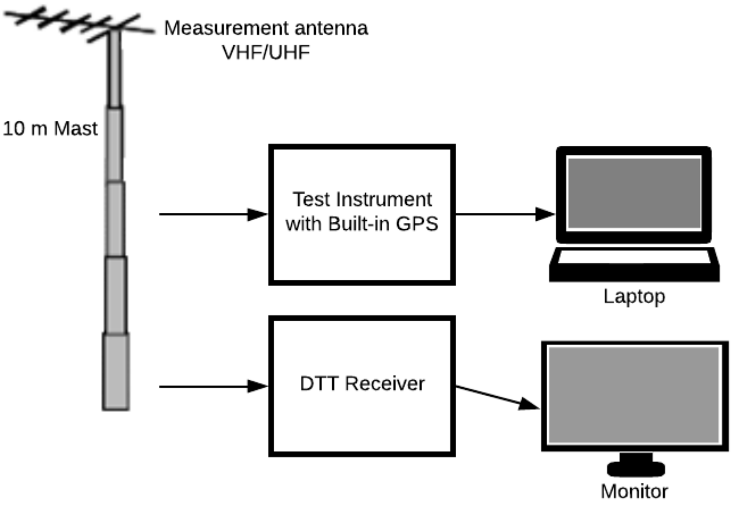

Figure 12. Survey measurement system. [16]

This methodology defines a convenient and practical measurement system that delivers reliable and repeatable results. It is desired that this kind of system be representative of domestic antenna installations, but not necessarily an exact replica. The recommended antenna parameters, contained in Appendix 3 of Rep. ITU-R BT 2035-2, are the following:

- UHF channels 28-69
- Phased array antenna
- Front back ratio of 20 dB
- Gain slope across any 7 MHz channel < 1 dB
- Impedance 75 ohms, VSWR > 1.6:1
- Half power beamwidth < 35º

It is possible that a UHF phased array “panel” type of antenna achieves those specifications and allows the development of a measurement system that adapts to the “test receiving system” specifications. Is considered that multi-element Yagi antennas may not be optimum for UHF measurement tests in some areas because of their narrow beamwidths, and difficulty in achieving and maintaining correct orientation, but they are more suitable for tests in rural areas, because the broader beam of a phased array means that the operator will have fewer problems with mast oscillations and overshoot on rotation in more populated environments.

Because of multipath propagation, is possible that the best signal will approach from different orientations on different channels, which means, when a long-yagi antenna is used it can be compromised the performance across all channels or requiring multiple antennas to achieve acceptable results. Due to the above, the use of a phased array antenna with broader horizontal beam may deliver good performance across all channels from a single antenna. As mentioned in Rep. ITU-R BT 2035-2, for DVB-T systems, it is more important to maximize the total channel power received within the guard interval than it is to minimize the reception of multipath signals, so the value of narrowbeam antennas is reduced compared with the analogue case.

The procedure to perform the measurement consist in upon arriving at each planned measurement location, the exact measurement location should be selected such that it is an average scenario of the observed in nearby residences. In metropolitan areas observe the average height of existing television antennas used in that area and make measurements at that height, as well as at 10 m.

It is important to guarantee that the measurement location is safe for the vehicle survey operators and is not a road hazard to passing traffic. It is necessary to examine the overhead power lines and overhanging trees, this and the terrain conditions and any obstructions should be documented for future evaluation. It is important to emphasize in the hazards of using a telescopic mast near power lines, and the dangers of driving away with the mast still elevated.

At each location, it is required to record the GPS references and note the geographic, climatic and environmental factors related to the location. If possible, take photos or video of the measurement location, as they may be helpful for future reference, showing the measurement area including the survey vehicle, also photograph the path in the direction of the transmitters, and of typical receive antennas in use by local viewers, to check in which direction are they pointing.

According Rep. ITU-R BT 2035-2, the measurement procedure to verify each broadcast transmission is the following:

- Place the appropriate antenna securely on the mast and raise the mast so that the antenna is 10 meters above ground level. Rotate, test and, if necessary, align the antenna to peak the signal on the test receiver; pass through the signal peak and back again to ensure you do not stop rotating the antenna on a side lobe. If possible, occasionally check that the spectrum shape for each digital transmission is substantially flat and if necessary, adjust the antenna pointing to achieve a reasonable shape compromise on all required channels.
- If the measurement location and route is within a single frequency network (SFN), for measurement purposes, it may be necessary to use a highly directional antenna on a steerable platform when it is desired to be able to identify the contributions made by each individual transmitter in the SFN.
- Record the measured voltage and, if possible, the spectrum shape for each required channel as well as for the complete group of transmissions.
- Also record the BER, MER and, if possible, impulse response for each digital transmission.
- If possible, evaluate the impulse response and record comments if there are complex echoes that could make decoding more difficult, and if practicable, capture both the image of the impulse response, and the image of the MER across subcarriers.
- To determine available operating threshold, insert a variable attenuator between the antenna cable and the test receiver input. Increase the attenuation in small steps until the BER before Reed Solomon (RS) as measured by the test receiver is just less than 2×10^{-4} recording the amount of attenuation in dB. Evaluate results and re-measure if necessary.
- While lowering the antenna, observe signal variations to determine if site is affected by ground reflections. As true free-space sites are rare, a small number of measurement sites under this condition are expected; and as many domestic antennas are mounted at less than 10 m, it is recommended that measurements are also done at other heights, to determine the contribution of multipath and other practical factors.

After the conclusion of the measurement procedure for a particular region, the results should be statistically analyzed and compared against the propagation prediction model. This analysis may help with the improvement of the model to minimize the difference between prediction and measured results.

4.1.5. Field survey methodology for nomadic measurement of digital television reception

This section describes the procedure to perform a “drive and park” measurement, as a solution to the dilemma faced by broadcasters and regulators to define a method for DTTB coverage determination which could be less time-consuming than taking measurements at 10 m with a telescopic mast. The objective is to record digital reception characteristics in a common format, such that different organizations could perform measurements and subsequent analysis allowing the comparison of DTTB coverage between studies. Dependent upon the accuracy of the measurement technologies, this methodology could also lead to capture larger amounts of data within a shorter time-frame.

According Rep. ITU-R BT 2035-2, the main objective of the process is developed for the testing of an instrument which allows “drive and park” surveying. The key features of this field survey methodology are:

- First, reference measurements are made at sites with a clear radio path at 10, 7.5, 5 and 2.5 m above ground level to the transmission facility, preferably in the direction of the main lobe of the transmitting antenna.
- Second, a “drive and park” measurement technique is employed where measurements are performed using the new measurements technologies at predetermined locations at 1.5-2 m above ground level. The measurement vehicle is driven predetermined distances on a selected route to capture a significant sample of measurement data at each site within the DTTB coverage location to determine fixed reception at each location on the route at 1.5-2 m.

The principal outcome of the process may lead to the introduction of these technologies to assist the future planning and better implementation of digital television services.

In relation with the equipment necessary for the test, they are the same as the ones described in section 4.1.4, because the difference between the fixed and the nomadic measurement methodology resides in the procedure.

In this case, the measurement procedure consists in upon arriving at each planned measurement location, the exact measurement location should be selected such that it is an average scenario of the observed in nearby residences. In metropolitan areas observe the average height of existing television antennas used in that area.

It is important to guarantee that the measurement location is both safe for the vehicle survey operators and is not a road hazard to passing traffic. It is necessary to examine the overhead power lines and overhanging trees, this and the terrain conditions and any obstructions should be documented for future evaluation. It is important to emphasize in the hazards of using a telescopic mast near power lines, and the dangers of driving away with the mast still elevated.

At each measurement point whether during a drive test or at a static location on the route of the drive test, it is required to record the GPS reference and observe the geographic, climatic and environmental factors related to the route. If possible, take photos or video of the measurement location, as they may be helpful for future reference.

According Rep. ITU-R BT 2035-2, the measurement procedure to verify each broadcast transmission is the following:

- Test and, if necessary, align the antenna to peak the signal on the test receiver; pass through the signal peak and back again to ensure you do not stop rotating the antenna on a side lobe. If possible, occasionally check that the spectrum shape for each digital transmission is substantially flat, and if necessary, adjust the antenna pointing to achieve a reasonable shape compromise on all required channels.

- If the measurement location and route is within a single frequency network (SFN) it may be necessary, for measurement purposes, to use a highly directional antenna when it is desired to be able to identify the contributions made by each individual transmitter in the SFN.
- Record the measured voltage and, if possible, spectrum shape for each required transmission.
- Also record the BER, MER and, if possible, impulse response for each digital transmission.
- If possible, assess impulse response and record comments if there are complex echoes that could make decoding more difficult, and if practicable, capture both the image of the impulse response and the image of the MER across sub-carriers.
- MER is used for drive-by reception testing, as DVB-T was not designed for mobile.
- If the antenna is height-adjustable and measuring at a static location, lower the antenna and observe signal variations to determine if the site is affected by ground reflections.

After the measurements, is recommended to evaluate the consistency of the results against the propagation model predictions. If no discrepancies are noted, the survey should proceed to the next planned measurement location. In case any anomalies are noticed in measured data, check the equipment and repeat measurements, and in the case that static measurements were performed choose different locations.

After the conclusion of the measurement procedure for a particular region, the results should be statistically analyzed and compared against the propagation prediction model. This analysis may help with the improvement of the model to minimize the difference between prediction and measured results.

4.2. Recommendations applicable to SUTEL

In this section is going to be analyzed which recommendations and procedures from the ones mentioned in the Rep. ITU-R BT 2035-2 would be applicable to the SUTEL, considering the needs and the limitations of the SUTEL to perform some type of procedures.

As mentioned in section 4.1.2, the guideline recommends a range of 20 to 100 measuring sites to obtain statistically significant results, in the case of a fixed outdoor scenario is recommended a minimum of 100 sites. Considering the previous and the fact that the SUTEL already performs a measurement procedure to verify the coverage of each service across the country by developing measurements in 212 preselected locations, as shown in Figure 13, the number of measuring sites defined by the SUTEL fulfill the requirements to evaluate the coverage of the DTT emissions with statistically significant results.

Due to the above, it is considered that the procedure to measure DTTB can be executed altogether with the existing procedures, something that is beneficial for the SUTEL, because optimizes several aspects as time, transportation, use of equipment and use of personnel.

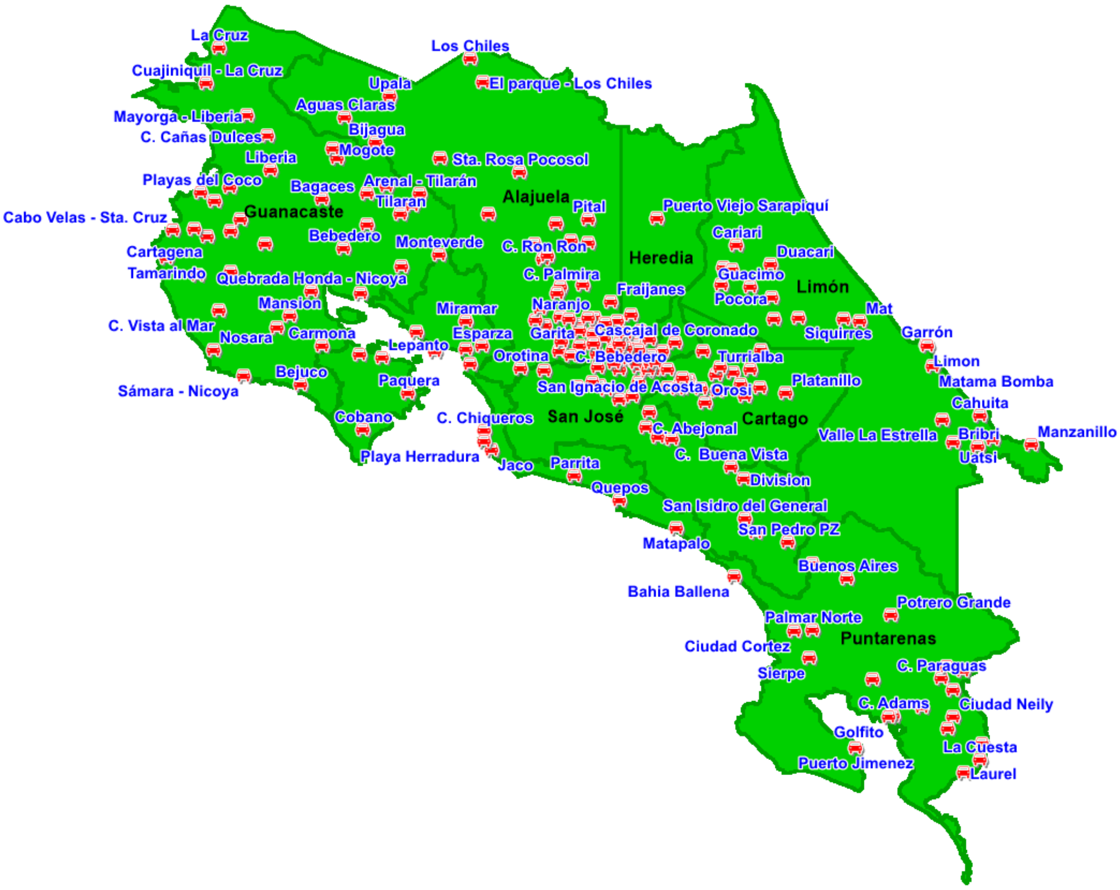

Figure 13. SUTEL measurement locations.

In order to determine which recommendations are applicable to the SUTEL is necessary to understand the resources available to perform the procedures, because of this is important to mention that the SUTEL has a broad system for spectrum monitoring that conforms the National System of Gestion and Monitoring of Spectrum (SNGME, from Spanish: Sistema Nacional de Gestión y Monitoreo de Espectro) [15]. This monitoring system consist on five fixed stations located in strategical positions around the country, and two mobile stations that allows to perform measurements throughout the country. The fixed and mobile stations represent a complement between them, allowing to perform different type of studies altogether, an example could be the application of direction finding using multiple stations at a time, to help identify the origin of a signal.

The equipment that can be found on the fixed and mobile stations are the following:

- Laptop with basic module of monitoring software R&S ARGUS of Rhode & Schwarz.
- Modular System Device base unit-MSD of Rhode & Schwarz.
- Digital direction finder and wideband receiver-DDF255 of Rhode & Schwarz.
- Signal and spectrum analyzer 10Hz to 7GHz-FSV of Rhode & Schwarz.
- TV Analyzer 500 kHz to 3 GHz with tracking generator-ETL of Rhode & Schwarz.
- Compass-IS20 of SIMRAD.
- GPS Receiver- GPS 17 of GARMIN.
- ISDB-Tb USB TV tuner.
- VHF/UHF wideband DF antenna 20 MHz to 3 GHz-ADD295 of Rhode & Schwarz.
- Active HF Rod Antenna, 9kHz-80MHz-HE010 of Rhode & Schwarz.

- Active Omnidirectional Receiving Antenna, 20MHz-8GHz-HE600 of Rhode & Schwarz.
- Broadband omnidirectional antenna, 800 MHz to 26.5 GHz-HF907OM of Rhode & Schwarz.
- Monitoring antenna system-MW-40 antenna of Rhode & Schwarz.
- Log-Periodic Antenna, 850MHz-26.5GHz-HL050S7 of Rhode & Schwarz.
- Compact U/SHF DF antenna, for single-channel DF-ADD207 of Rhode & Schwarz.
- Log.-periodic broadband antenna, 80MHz to 2000MHz-HL033 of Rhode & Schwarz.

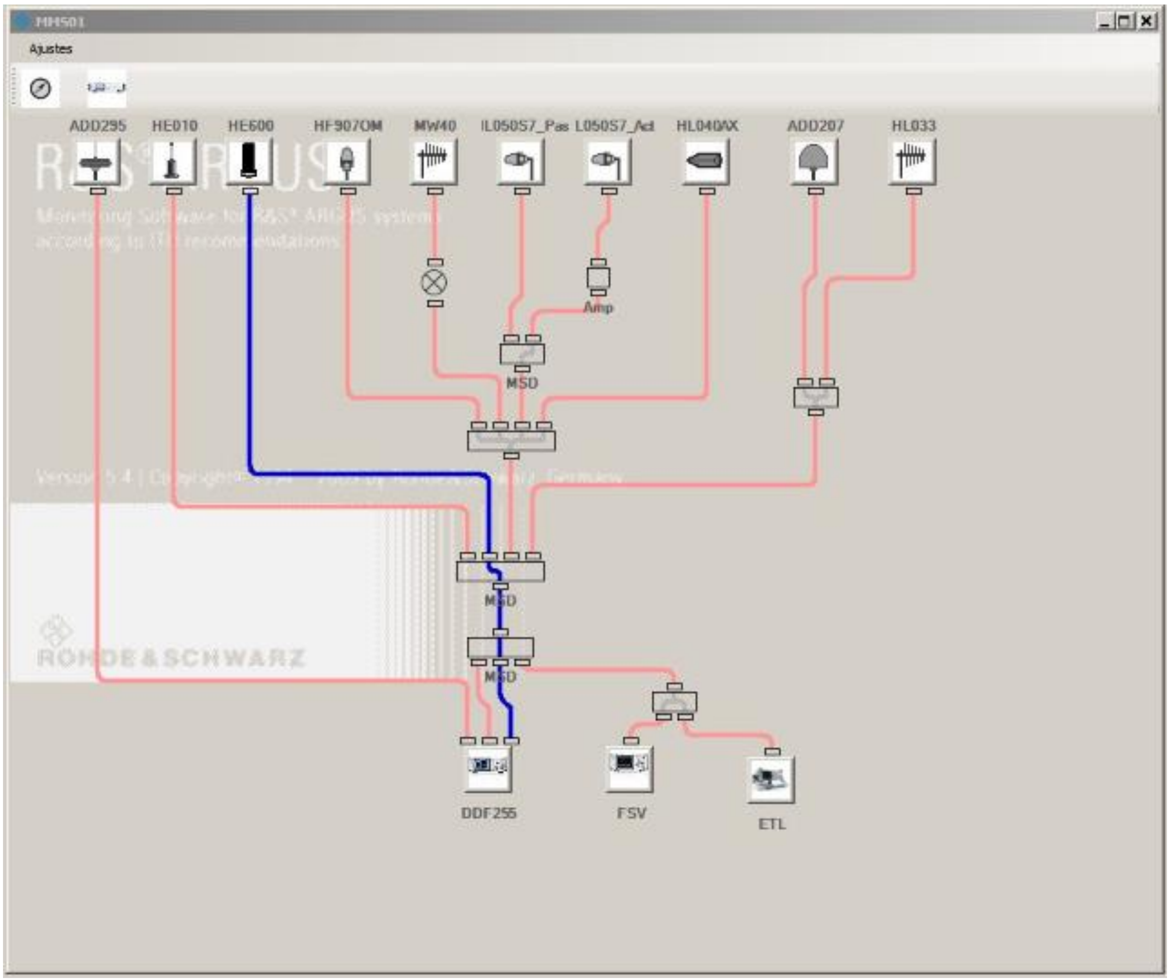

Figure 14. Diagram of equipment in mobile station

Is important to mention that each station has a computer with the monitoring software R&S Argus, that allows to operate all the equipment from the computer, select the different antennas and program automated measuring routines, as shown in Figure 14, where can be observed the R&S Argus interface showing the equipment and antennas available in one of the mobile stations. In the case of the mobile stations, they also count with a telescopic mast that can reach a height of 8.5 m approximately.

As mentioned in sections 4.1 and 4.1.2, according Rep. ITU-R BT 2035-2, there are several receiving modes that can be considered for the tests, however because SUTEL already performs coverage measurements for all the allocated spectrum in fixed outdoor mode, it is desirable to maintain this mode for the measurements for DTTB.

In relation with the antennas required, in section 4.1.4 are described the general aspects about different types of antennas that can be considered for each type of measurement that can be performed in a fixed outdoor mode. Probably the most important aspect described is how a highly directional antenna can be applied to obtain the contribution made by an individual transmitter in an SFN scenario, situation that can be complex due to the need of steering and alignment of the antenna to perform a proper measurement because of the narrow beamwidth that they possess. An option to avoid the mentioned complexity is the implementation of a phased array "panel" type antenna that has a broader beamwidth that is less sensitive to the mast oscillations and overshoots during rotation. In the case of the SUTEL, these complexities can be magnified due to the requirement of measuring all the DTT channels at each site in a single run.

Considering that in DTTB is more important to maximize the total channel power received within the guard interval than it is to minimize the reception of multipath signals as it was in analogue broadcasting, a multi-element yagi antenna will have a compromised performance in a multipath propagation scenario, which means that they are unsuitable with the scope of the SUTEL.

Taking into account the last remark, the fact that performing the evaluation on individual transmitters is out of the scope of the measurements that SUTEL require to implement and the specification of measuring all the DTT channels at each site in a single run, the best performance will be probably achieved with an omnidirectional antenna. From all the equipment contained in the stations, the only antenna that can measure in the range of the UHF TV band and fulfill the characteristics mentioned before is the HE600 antenna, so it is the one recommended to be employed in the measurements.

The next parameter that requires to be defined is the antenna height for the measurements, as described in section 4.1.4, the typical recommended value for the antenna height for fixed outdoor measurements is 10 m, but is also recommended to observe the average height of existing television antennas used in that area and make measurements at that height. In order to try to define an average measuring height for Costa Rica, is necessary to consider that in Costa Rica the urban development is composed mostly by one story structures, situation confirmed by the statistics of construction developed in the country by the National Institute of Statistics and Censuses (INEC) [17] the years between 2016-2018 in which 80 % of the constructions developed during those years were of one story. Also, the Construction Regulation [18] in the article 158 establishes that the minimum height between floor and ceiling is 2.4 m and 2.6 m the distance between floor and roof top when there is no ceiling, so considering that the height between the ceiling and the roof top goes in the range of 1-2 m and the antennas are usually installed over the roof top in mast with a height between 0.5-1 m, it can be established that the typical antenna height in Costa Rica will probably be in the range of 3.1-5.4 m. Considering the previous, it can be established that the average antenna height in Costa Rica is approximately 4 m, recommendation that probably turns the measurements at 10 m unnecessary because it is considered that measuring at the average antenna height is more representative from a typical reception scenario than measuring at 10 m, so the recommended measuring height is 4 m.

Other important aspect to highlight, as mentioned in section 4.1.5, is the recommendation of a methodology in which the procedure is designed as a solution to the dilemma faced by broadcasters and regulators to define a method for DTTB coverage determination which could be less time-consuming than taking measurements at 10 m with a telescopic mast.

The procedure consists on taking reference measurements at four different heights above ground level (10, 7.5, 5 and 2.5 m) with a clear radio path and then perform a “drive and park” technique where measurements are performed at predetermined locations at 1.5-2 m above ground level over a selected route.

It would be very beneficial for the SUTEL to perform an adaptation of the procedure mentioned above, which means that the proposed protocol avoids performing measurements with a telescopic mast because is considered that the implementation of this in the 212 measuring locations would be impractical and time-consuming. But there is an inconvenient with the adaptation of the mentioned procedure, because of the requirements of the SUTEL of measuring all the allocated broadcasters on a single run, which turns unpractical and time consuming the “drive and park” measurement technique.

Taking into account the previous remarks and the fact that the actual procedure performed by the SUTEL consist of using the antenna HE600 located at the rooftop of the vehicle to perform coverage measurements, is necessary to determine if this antenna height of approximately 2 m is the optimal to perform DTTB coverage measurements or it will be necessary to locate the antenna at a higher height or even perform measurements at multiple heights. Due to the above, is necessary to perform an study to determine the optimal measuring heights by performing reference measurements as mentioned in section 4.1.5, but in this case the antenna heights will be 8, 6, 4 and 2 m because of the physical limitations of the mast that has a maximum reach of 8.5 m of height, and determine by statistical analysis which is the height that allows the best reception of DTT.

In relation with the time of measurement, in the section 4.1 is mentioned the general recommendations of the different field test procedures, and indicates that according Rep. ITU-R BT 2035-2 the test durations can be classified as very short term, short term, long term, very long term and seasonal. Considering that the main objective of the protocol is to verify coverage and that the recommendation established that the measuring time for coverage measurements should be classified as short term, that implies that the measuring time should be between a few seconds and a few minutes, also considering that in the Recommendation SM.1875-2 with the title “DVB-T coverage measurements and verification of planning criteria” [19] is indicated a minimum measuring time of one minute for coverage measurements, because of those recommendations it has been chosen the measuring time of one minute as the suggested value for the protocol proposal.

As for the parameters that are required to be measured, at the moment it is established in the regulations that the only parameter that requires to be measured is the signal level, and it is established that the minimum level allowed corresponds to 60 dBµV/m, but nevertheless in section 4.1.4 is recommended to record the BER, MER and, if possible, the impulse response. Therefore, it is desired to perform an analysis of this parameters during the study suggested above, that will perform measurements at different heights, to determine the impact of the height into them. It is important to mention that this are the suggested technical parameters related the received signal but there is also important to record all the possible geographical data from the measuring location.

Considering the previous, after the study is executed it will be necessary to perform an analysis of the results to determine if the variation of the measuring height has influence in each of the parameters that are monitored and how they describe the behavior of the received ISDB-Tb emissions, therefore, describe how the reception is influenced by the antenna height.

As mentioned above, the equipment available for DTV measurements is the ETL developed by Rhode & Schwarz. In Figure 15 can be observed the general parameters that the equipment can identify for each measured channel, and in Figure 16 can be observed the parameters that the equipment can identify for each layer of the measured channel. Between the general parameters that can be obtained from the equipment, some of them are the signal level, mode, guard interval, MER (RMS, Peak, TMCC and AC) and many others. For the case of each layer, some of the parameters that can be obtained are the modulation, code rate, time interleaving, number of segments, MER per layer (RMS and Peak), BER per layer (before Viterbi, before Reed-Solomon and after Reed-Solomon), packet error rate and MPEG Transport String Bitrate.

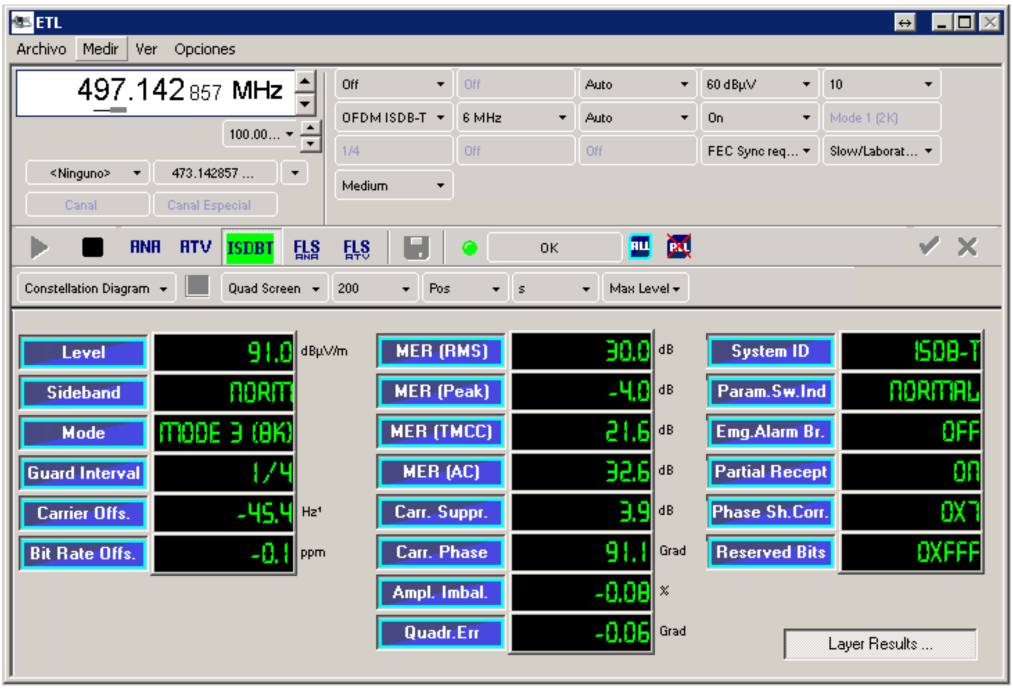

Figure 15. R&S ETL's parameters available for ISDB-Tb service.

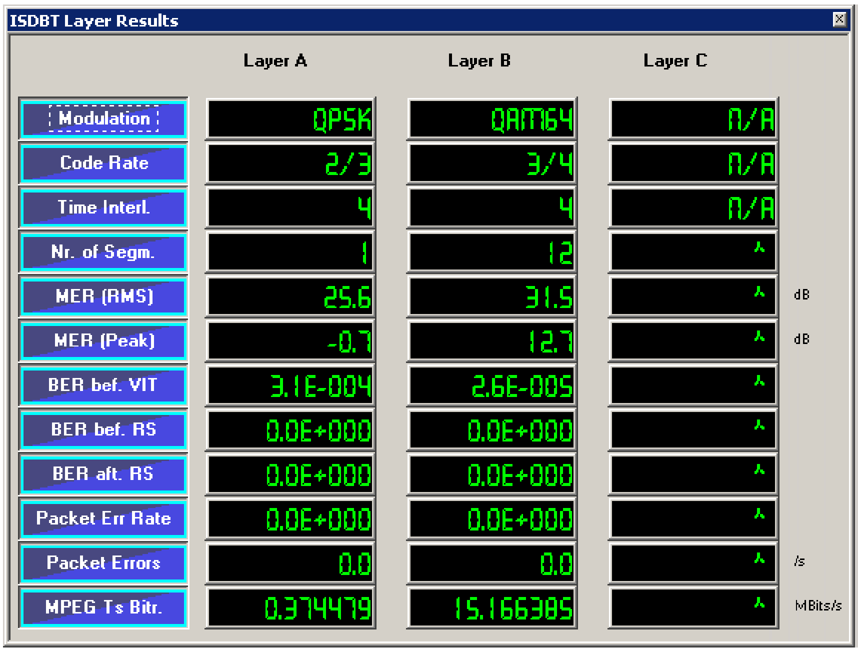

Figure 16. R&S ETL's parameters available for each layer of ISDB-Tb service.

As mentioned before, the parameters required to be measured are the signal strength, BER, MER and, if possible, the impulse response. After observing all the capabilities of the ETL equipment, is determined that all the parameters could be measured, but from practical point of view, the impulse response is measured by different mode than the rest of the parameters which is unavailable in the R&S Argus software and the information provided by the impulse response is out of the scope of the protocol proposal. Because of the previous reasons, the impulse response is discarded as a required parameter.

From the practical point of view the signal strength, BER and MER can be measured with the same mode and they are available to be selected in the R&S Argus software, as observed in Figure 15 and Figure 16, every time the software stores a measurement value, it stores a value for the signal strength, BER, MER and all the other parameters that were selected in the software. The inconvenient with the BER reside in the fact that is a parameter that is measured by layer, this implies that amount of data to analyze increases, so in order to perform a general evaluation of the channel, as is required by SUTEL, the analysis of the BER is discarded, which means that the only parameters that will be analyzed from all the ones delivered by the ETL are the signal strength and the MER, but the BER and other parameters can be documented just in case they are required in future studies.

In order to evaluate the MER, according to C. Klaus [20], "a high MER value indicates good signal quality. In practice, the MER lies in the range of only a few dB to around 40 dB. A good ISDB-T transmitter has a MER in the range of approximately 35 dB. When receiving ISDB-T signals over a roof antenna with gain, a MER of 20 dB to 30 dB would be measurable at the antenna box. Values between 13 dB and 20 dB are expected for portable receivers with a room antenna." Is important to consider that the minimum level of MER allowed will depend on the modulation implemented, in the case of a 64 QAM the minimum MER recommended is 23 dB measured at the antenna.

After all the considerations performed, in Table 3 can be observed the summary of the parameters that were analyzed and the conclusions developed about them.

Parameters	Can be measured automatically with R&S Argus?	Can be processed statistically in a simple way?	Recommended Threshold
Signal Strength	Yes	Yes	≥ 60 dBuV/m
MER	Yes	Yes	≥ 23 dB
BER	Yes	No	-
Impulse Response	No	No	-

Table 3. Parameters to be measured.

4.3. Measurement Results

Considering the conditions mentioned before, it was necessary to perform a study to determine the optimal measuring heights by performing measurements at four reference heights which are 8, 6, 4 and 2 m. The antenna that was placed on the mast was the HE600 which is an omnidirectional antenna as mentioned before. The parameters that were established to be measured are the signal strength, MER and BER, besides several other parameters that the ETL can display on the same measurement as the mode, guard interval, modulation, code rate, time interleaving and number of segments.

As mentioned before, the parameters that are going to be analyzed after the measurements are the signal strength and the MER, with the intention of observing their behavior at different heights. In order to observe the behavior along the UHF TV band it will be required to measure one channel at the low, middle and high part of the band, so the study will consist on performing measurements of three channels that are already transmitting in ISDB-Tb in Costa Rica.

After analyzing which broadcasters have a valid license to an experimental network of DTT and that are known for transmitting continuously, is determined that the channels that are going to be measured are 18, 30 and 49, with the respective central frequencies at 497.142857 MHz, 569.142857 MHz and 683.142857 MHz.

At the beginning of the study it was of knowledge that the three broadcasters were operating with a single transmitter each, and all the transmitters were located in a nearby region, so it was expected to have very similar scenarios for the three broadcasters, but at the beginning of the field test it turned out that the owner of channel 18 have extended his network, as a result, know the scenario for channel 18 corresponds to a SFN instead of a single transmitter as in the case of channel 30 and channel 49.

Before the field test, it was necessary to identify the locations that were inside the expected coverage of each channel at the different reception antenna heights that were selected, this was accomplished with the simulations that were performed for each channel with the known transmission parameters, as can be observed in Appendix 1. Beside the coverage area, with these simulations it was obtained the expected field value at all the locations in order to compare with the values obtained on the field.

From the coverage simulations for the three channels, it is obtained that from the 212 sites that are annually measured by the SUTEL that the maximum of sites that would have coverage for any of the channels are 103 measuring sites, then, if the method for obtaining the sample size for estimating a proportion is applied, considering that the coverage simulation gives a high probability of obtaining the minimum signal level required of 60 dBuV/m so it will be considered a proportion of 95%. In order to obtain results with 5% of error with a confidence level of 95% it is necessary to measure a sample of at least 43 locations.

During the field test 45 locations were measured to fulfil the determined sample size, the coordinates of the locations are the following:

Location Name	North Latitude	West Longitude
Cerro Bebedero	9.907972	84.162667
Cuidad Colón	9.914139	84.242556
Escazú	9.949322	84.163924
San José	9.936722	84.102806
Santa Ana	9.932167	84.181583
Calle Blancos	9.950143	84.068728
Curridabat	9.909808	84.040042
Guadalupe	9.946868	84.055594
Hatillo	9.917424	84.094703
Moravia	9.960514	84.046258
Pavas	9.946590	84.127245
Rohrmoser	9.939764	84.108299
Sabana	9.929898	84.101077
San Franscisco de Dos Ríos	9.908915	84.059449
San Pedro	9.933094	84.050500
Tibás	9.957593	84.081713
Uruca	9.956465	84.113327
Vargas Araya	9.937083	84.030222
Garita	9.992036	84.310334
Grecia	10.073290	84.311452
Guacima	9.966863	84.246992
Poás	10.076250	84.245444
Puente de Piedra	10.047282	84.309141
Tambor	10.035394	84.256312
Alajuela	10.019583	84.217306
Turrúcares	9.958223	84.341620
El Coyol	10.000357	84.259101
San Rafael de Oreamuno	9.867726	83.909438
Cartago	9.863869	83.921921
Aguacaliente	9.848701	83.910553
Guadalupe de Cartago	9.859742	83.940027
Tejar	9.843858	83.935587
Tobosi	9.840848	83.986212
Tres Ríos	9.907667	83.985556
El Guarco	9.838566	83.950609
Taras	9.876466	83.934000
Barva	10.020686	84.125467
Heredia	9.998917	84.117028
Lagunilla	9.978771	84.125996
Mercedes Norte	10.009418	84.126459
San Antonio de Belen	9.978361	84.185611
San Pablo	9.996806	84.106750
Santa Barbara	10.036861	84.159417
Santo Domingo	9.977467	84.092723
Malinche	9.987497	84.139350

Table 4. Measurement Locations.

Before the execution of the field test, it was necessary to determine the configuration of each parameter of the ETL on the R&S Argus software in order to obtain the expected measurement results. The first thing is to select the ISDBT mode in the Argus and this will indicate which parameters can be configured, some of them are fixed like the TV Standard and Channel Bandwidth, but others require to be configured.

For example, some of them were tested to observe how they influenced in the measurement, in the case of the Preamplifier it was observed that in some cases when it was on the ETL failed to demodulate the DTT signal, so it was established that the Preamplifier should be set OFF. The Side Band Position and the FR Attenuation were set to AUTO, the Expected Level was set in 60 dBuV, the TMCC detection was set to ON, it was habilitated the FEC Sync required, the system optimization was set to Slow/Laboratory and the Min BER Integration was set to 10 samples.

As mentioned before, the recommended measuring time for fixed outdoor measurements should be between a few seconds and a few minutes and other recommendations established that the measurements should be at least one minute for coverage testing, so it was recommended a measuring time of one minute but it was required to verify if this time was sufficient or if longer measurement times could have an impact in the average results, so measurements were performed with time values between 1 to 10 minutes and one measurement of 30 minutes, and after comparing the average values it was observed that the average values for all the measurements were similar, so it is considered that a measuring time of one minute is sufficient.

At each location a measurement of at least one minute was performed for each of the selected channels at every established height, as shown in Figure 17, it is important to mention the chosen measuring heights are at 2.5 m, 4 m, 6 m and 8m. The measuring height of 2.5m is because this is the minimum height that can be achieved with the telescopic mast when it is installed in the vehicle, also the maximum height that can be achieved with the mast about 8.5 m, so the height of 10 m cannot be achieved with the equipment available for the SUTEL.

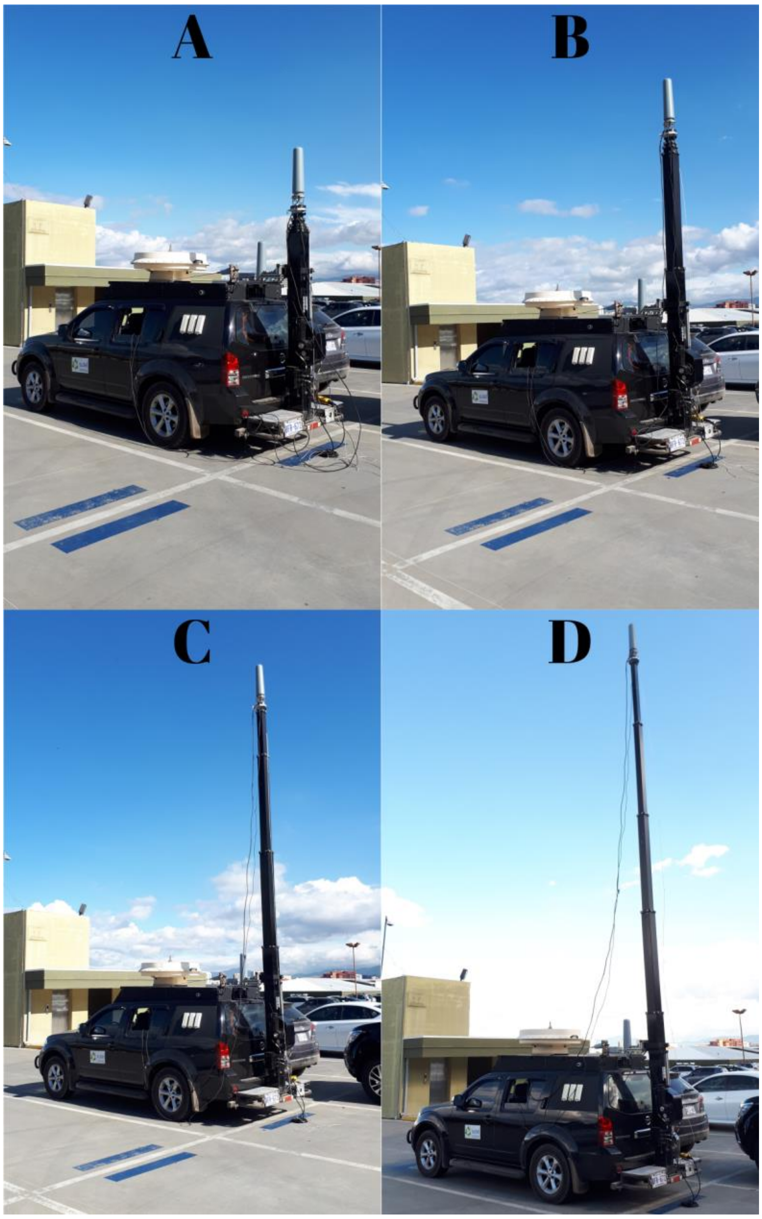

Figure 17. Field test measuring heights (A at 2.5 m, B at 4 m, C at 6 m and D at 8 m).

In Figure 18. Field test system implementation.Figure 18 can observed the system that was implemented to perform the field test during the research. Consisted in using the antenna HE600 in the telescopic mast, and the signal obtained in from the antenna was sent to the ETL and to an ISDB-Tb Receiver. The receiver is a USB type that allows sending the received signal to the laptop where is also controlled the measurement performed by the ETL. This configuration facilitates the observation of the measurements and the DTV signal from the same laptop, helping to monitor the coherence between the signal and the measurements.

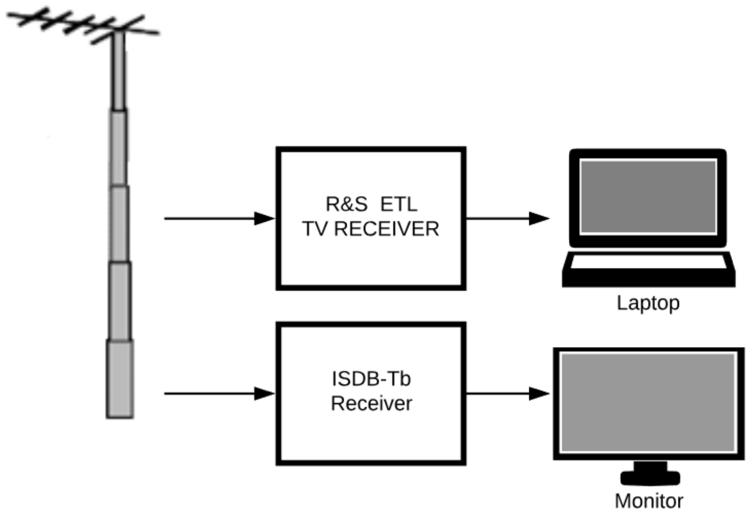

Figure 18. Field test system implementation.

The procedure performed consisted in measuring, at each location, the three selected channels for the period of one minute each at the four defined heights, the complete set of results can be observed in Appendix 2. After performing the procedure in the 45 selected sites, it is performed a statistical analysis of the results that can be fully observed in Appendix 3.

First, it was performed a scatter plot for all the measurements using the variables signal level and MER, and using a color scale for the channels, where was observed that channel 18 apparently have a behavior that is different from the other channels, to prove that is necessary to perform an analysis of variance to demonstrate if channel 18 has a significant difference against the others. From the analysis of variance, it is obtained that there is a significant difference from the results of channel 18 in comparison with channel 30 and 49, in both variables, situation that was expected due to the knowledge that channel 18 was operating as an SFN. In this case, it can be interpreted as a comparison between an SFN and single transmitters network, but because only one SFN network was measured this is a false generalization, it will be necessary to perform future measurements over more SFN networks to prove it.

After this conclusion, in order to perform further analysis, the channels are grouped in channel 18 as the first group and channels 30 and 49 as the second group. Then a second analysis of variance is performed over the variable height and the two groups, that throws the conclusion that for channel 18 the measured results are independent from the height for both variables, signal strength and MER, but for channels 30 and 49 the measured results are classified in three groups for the signal strength and two groups for the MER, which means that for this case there is a difference in the results depending on the measuring height.

Considering that the simulations show that the signal level should follow a behavior of decreasing intensity according to the decrease in the measuring height, it draws attention the fact that are several locations in which the behavior of the signal level is the opposite from the one described by the simulations, and the behavior of the MER is the same as the signal level. Due to the above, it where performed some additional measurements in two sites to verify if the behavior recorded in the first measurement was maintained, these measurements can me observed in the Appendix 2.

From this results it is observed that the quality of the signal is highly dependent to the noise level observed in the site, which means that a measurement with high signal level could present a low MER scenario, even could be uncapable to correctly receive the signal; and in other cases, a measure with low signal level could present an adequate MER value, allowing the correct reception of the signal. This demonstrates that the signal level and the MER are unrelated, and they are different at every location due to the different propagation scenarios.

Taking into account the variability of the signal strength and MER on each location due to the different propagation scenarios, it is necessary to evaluate the results delivered by the analysis of variance. As it was already mentioned, for channel 18 there is no significant difference in both variables, so it can be considered that measuring at 2m or at 8m is the same from the statistical point of view. Even though, when the mean values for the different heights are observed, the difference for the signal strength between 2m and 8m is of 3.7 dB, but the lowest value is at 4 m which is 0.2 dB lower than 2 m. In the case of MER, the highest value is achieved at 2 m and the worst at 4m with a difference of 1.35 dB, while the difference between 2 m and 8 m is just 0.58 dB.

As already mentioned, in the case of channel 30 and 49, was identified that there are significant differences in the values obtained at different heights, so the results can be classified in three groups for the signal strength and two groups for the MER. For the signal strength is observed that there is no significant difference between 2 m and 4 m, and at the same time that there is no significant difference between 4 m and 6 m, but 8 m is significantly different from all the other data. In the case of MER is observed that there is no significant difference between the data at 2, 4 and 6m, and that there is no significant difference between 6 m and 8 m. In the case of the signal strength the highest mean value is achieved at 8 m and the lowest at 2 m with a difference of 6 dB, while the difference between 2 m and 4 m is 1.7 dB. For the MER the highest mean value is achieved at 8 m and the lowest at 2 m with a difference of 1.62 dB, while the difference between 2 m and 4 m is 0.12 dB.

As it has been shown, for both cases channel 18 and channels 30 and 49, the improvement between measurements at 4 m and 2 m is low, even in the case of channel 18 the signal strength and the MER are better at 2 m. So in case that is necessary to perform measurements at 4 m because is considered as the expected average height at which antennas can be found in Costa Rica, from the statistical point of view there is no significant improvement in measuring at 4m so it is recommended to perform measurements as 2 m.

Another fact observed in the field test is that the parameter that is directly related with the possibility of demodulating the DTT signals is the MER, so it is recommended to consider the MER as the first criterion to evaluate the DTTB emissions, over the signal strength which is also important to measure because in locations where the MER is enough to demodulate the signal but the field strength is low, this locations are sensitive to interferences, channel variations and echoes that can convert the situation into a no reception scenario.

4.4. <u>Measuring protocol proposal</u>

In this section it will be established the steps that are required to perform measurements of DTTB in Costa Rica, this first draft of the protocol like any measurement protocol of the SUTEL, it has to satisfy with all the procedures and guidelines established in the resolution N° RCS-199-2012 with the title “General Protocol for Measurement of Electromagnetic

Signals” [21] and also has fulfil the objectives and blend with the procedure N° DGC-CA-PROC-15 that has the title “Measurements of coverture of spectrum using the fixed and mobile stations of the SNGME” [22].

The equipment necessary to perform the procedure to measure coverture of DTTB are the following:

- Laptop with basic module of monitoring software R&S ARGUS of Rhode & Schwarz.
- TV Analyzer 500 kHz to 3 GHz with tracking generator-ETL of Rhode & Schwarz.
- Compass- IS20 of SIMRAD.
- GPS Receiver- GPS 17 of GARMIN.
- ISDB-Tb USB TV tuner.
- Active Omnidirectional Receiving Antenna, 20MHz-8GHz-HE600 of Rhode & Schwarz.

As mentioned in section 4.3, some tests were performed in order to determine the configuration of all the parameters in ETL TV Analyzer. The recommended configuration is the following:

- Preamplifier = OFF
- The Side Band Position = AUTO
- FR Attenuation = AUTO
- Expected Level = 60 dBuV
- TMCC detection = ON
- FEC Sync required = SELECTED
- System Optimization = Slow/Laboratory
- Min BER Integration = 10 samples.

The automatic measurement routine that will execute the measurement procedure for ISDB-Tb is required that have configured all the parameters as described above

It is important to mention that from the measurement results and from several considerations on the objectives and limitations of SUTEL to perform some type of measurements, it has been established some conditions on the protocol for measuring ISDB-Tb by SUTEL.

In relation with the measuring height, as it was mentioned in section 4.2, the average height at which is expected to find an antenna in Costa Rica due to the average housing situation is approximately 4 m. But considering the results obtained from the field tests, for both cases of channel 18 and channels 30 and 49, where the results obtained at 2 m and 4 m for signal strength and MER are not significantly different between which means that measuring at 2 m is the same as measuring at 4 m from an statistical point of view, so the recommended measuring height is 2 m.

From the results it has been observed that the parameter that has direct influence in reception of the signal is the MER, also is the parameter that shows less variations between the measuring heights, so it is recommended the MER as the first criterion to evaluate the DTTB emissions. The signal strength is also important to measure because scenarios, with adequate MER but low signal strength, are sensitive to interferences, channel variations and echoes that can convert the situation into a no reception scenario.

In order to perform the measurement, as in other procedures followed by the SUTEL [22], is necessary to program an automatic measurement in the R&S Argus in order to assure that all the personnel in charge of the measurements deliver standardized results that allow to evaluate the coverage of each channel. The Automatic Measurement Mode requires that each parameter to be measured is declared individually, so in this case the routine should include, as minimum, the signal level and MER (RMS), but it can also be included the Mode, Guard Interval, MER (Peak, TMCC and AC), Modulation, Code Rate, Number of Segments, the MER by layer (RMS and Peak) and the BER by layer (before Viterbi, before Reed-Solomon and after Reed-Solomon) as information that can be useful in the future for further analysis.

Considering the analysis performed, in Table 5 can be observed the recommendation of each parameter that has to be considered in the measurement protocol.

Parameter	Recommendation
Antenna type	Omnidirectional
Antenna height	2 m
Measuring time	1 minute
Signal Strength	≥ 60 dBuV/m
MER	≥ 23 dB

Table 5. Configuration and measurement parameters.

Considering that the automatic measurement routine will be ready to be executed in the mobile station, the steps of the procedure to measure DTTB are the following:

- Check that all the connections with the laptop to perform the test are in place, immediately, turn on the laptop and the ETL and wait for all the equipment to perform their start up. Once all the equipment has started, execute the monitoring software R&S ARGUS and perform an autotest to verify that the communication with all the equipment has been established.
- Then enter the “AMM-Automatic Measurement Mode” and select the routine with the name “TV Digital”.
- On the selected routine, modify the “Result File” to the correspondent “Site Code” established for each measuring location.
- Once inside the routine is necessary to modify the schedule, so is necessary to define the actual date of the measurement set the starting hour and set the final hour to measure each channel for 1 minute, right now are 16 operative channels but in the future, it could be up to 36 channels.
- The system configuration allows to observe the channel contents while the automatic measurement is been executed, so it is recommended to observe the which channels operate correctly and document it with screen captures in order to verify the consistency of the measurements performed with the ETL and the reception conditions.
- After the measurement is finished, go to the “Explorer” inside Argus and verify that there is a file with a name that start with the same “Site Code” that was defined at the beginning of the test, click the “View” bottom and verify that the file contents all the measurements for all the channels. In case the measurement was faulty, repeat the autotest an verify that every equipment necessary is working properly and

restart the automatic measurement. Is important to delete the old file from the "Explorer" in order to be allowed to use the same "Site Code".

- After verifying that the result file is correct, go to Import/Export inside the "Explorer" select the File Format as Text File(*.csv) and then export the result file in the desired location.

As mentioned before, from all the parameters that are programmed in the automatic routine to be captured, the ones that are required to evaluate the service of each DTT network are the signal level and modulation error rate (MER). According to the PNAF [12] the minimum signal level allowed is 60 dBµV/m, the recommended value for the MER is 23 dB in a fixed outdoor mode configuration.

5. Conclusions and future development

In this section are presented the conclusions obtained from the investigation, and the recommendations for future researches that can be related to this thesis, based on the results obtained and the difficulties suffered along the process.

The conclusions for the research are the following:

- From all the parameters that can be measured it was determined that the required to appraise the ISDB-Tb emissions are the signal strength and the MER, because they are simple to be acquired with the ETL and they provide enough information to evaluate the received signal. It recommended that all the data provided by the ETL is saved for future studies like the BER per layer.
- From the data it is observed that there is difference in every location between the behavior of channel 18 that operated in an SFN scenario and channels 30 and 49 that operated in a single-transmitter scenario, because in the single-transmitter scenario it is observed that usually the worst signal level and MER it is obtained at the low measuring heights, but in the SFN scenario worst signal level and MER of a location is usually obtained at different heights, showing that the multi-propagation effect of an SFN scenario could have a significant impact in the received signal level and the measured MER.
- Even thought it was measured a channel operating as an SFN and two operating in a single transmitter scenario, from the results is difficult to assure that the behavior presented by the channel 18 and channels 30 and 49 will be the general scenario. It is required to perform measurements in more channels operating as an SFN to determine in the behavior of channel 18 can be considered as a general SFN scenario or it is a particular case.
- The difference in the behavior of channel 18 that operated in an SFN scenario and channels 30 and 49 that operated in a single-transmitter scenario is demonstrated by the analysis of variance performed to the variable channel, that showed that the three measured channels can classified into two groups. Due to the significance obtained from multiple comparisons test, channels 30 and 49 can be joined into one group and channel 18 represents another group by itself, proving that the SFN and a single-transmitter network present different coverage behavior.
- From the statistical analysis it is obtained the influence of the height over the signal strength for each case. In the case of channel 18 that operated in an SFN scenario it is obtained that is indifferent the height at which the measure is performed, but in the case of channels 30 and 49 that operated in a single-transmitter scenario the results can be classified into three groups: the results at 2 m-4 m, at 4 m-6 m and at 8 m, so it can be considered that in this case there is an impact in the results by performing measurements at different heights.
- For the MER is obtained a similar result for the influence of the height. In the case of channel 18 that operated in an SFN scenario it is obtained that is indifferent the height at which the measure is performed, but in the case of channels 30 and 49 that operated in a single-transmitter scenario the results can be classified into two groups: the results at 2 m-4 m-6 m and at 6 m-8 m, so it can be considered that in this case there is an impact in the results by performing measurements at different heights.

- From the data obtained during the field tests, can be demonstrated that the signal level and MER are independent variables for the different locations, heights and channels. Therefore, it is necessary to measure the signal level and MER in order to perform a proper evaluation of DTT emissions. Considering the above, in Costa Rica the actual evaluation criteria for DTTB, in which is monitored only the value of the signal level, should be considered as inadequate to provide enough information to evaluate the quality of a DTT network.
- As a general conclusion of the procedure performed, it was observed that is a significant difference between the behavior of channel 18 that operated in an SFN scenario and channels 30 and 49 that operated in a single-transmitter scenario. The measurements showed that signal level and the MER were significantly better for the case of channel 18. Then, the statistical analysis demonstrated that the measurements at different heights were related for the case of channel 18, so if it is considered that the SFN configuration will be massively used in the future and that all SFN's will have a behavior similar to channel 18, then, the optimal measuring height is at 2 m in terms of being less time and resource consuming and that the influence of the measuring height over the results remains irrelevant for the SFN scenario.
- Another general conclusion of the procedure performed is that the measuring height could be defined as an average antenna height expected in Costa Rica, and as it was mentioned the average antenna height can be established as approximately 4 m. But from the statistical analysis performed it was observed that, in both cases channel 18 and channels 30 and 49, there is no significant difference between the values obtained at 2 m and 4 m for signal strength and MER. Even in the case of channel 18 are obtained better values at 2 m than 4 m. So, in the case of selecting to perform measurements at average antenna height it would be recommended to measure at 2 m because from the statistical point of view is the same as 4 m.

The recommendations obtained from the research are the following:

- Considering that in Costa Rica the only evaluation criteria for DTTB is the received signal level, and that has been proved that signal level by itself is not enough to evaluate the quality of the reception, it is recommended to incorporate the measurement of the MER as another parameter to evaluate the quality of a DTT transmission.
- In the future when the broadcasters have fully deployed their networks for providing coverage to all the country, is recommended to perform a similar study considering more channels with an SFN network to verify if their behavior is similar to the one observed in channel 18.
- Also in the future case of fully deployed SFN networks, is recommended to expand the measuring locations to consider sites outside of the urban area in order to compare de behavior of the reception in urban and rural scenarios, and observe if there is a relation between the rural reception with the single-transmitter network scenarios.
- The recommended protocol has a close scope of application because of the requirements that were needed to fulfill but may appear different requirements for other type of measurements, like attending complaints for bad reception, so, it is recommended to establish an additional protocol that allows to perform more specific measurements to evaluate the receivability of a DTT network in a more detailed manner.

- In order to improve the results from the research, it will be better to count with the support of a statistician along all the research, with the final purpose of having a better advice related with defining the size of the sample population and the amount of samples per measurement, and perform a deeper analysis of the measuring results.

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Appendix 1. Simulations

In this section will be displayed all the simulation results obtained for the studied channels at different heights. It is important to mention that at the beginning of the research it was thought that the three broadcasters that operated the channels that were going to be measured were operating with only one transmitter, but the broadcaster of channel 18 was already operating an SFN network, so this was considered at the moment of performing the simulations.

The selected method for performing the coverage prediction of the broadcasters in Costa Rica is the ITU-R P.1546-5 that details a “Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz”. This model is the one selected in the software Chirplus BC in order to perform the simulations.

Now it is proceeded to show the parameters and the simulation results for each channel.

Channel 18

For the simulations of channel 18 were considered the two transmitters that give coverage to the area where the measurements were performed.

PARAMETERS	TRANSMITTER 1	TRANSMITTER 2
Name of location	Volcán Irazú	Rancho Redondo
Location	Cartago, Oreamuno, Santa Rosa. North Latitude: 09°58’17,06” West Longitude: 83°51’35,07”	San José, Goicoechea, Rancho Redondo. North Latitude: 09°57’30,0384’’ West Longitude: 83°57’10,3284’’
Digital standard	ISDB-Tb	ISDB-Tb
Central frequency (MHz)	497	497
Bandwidth (MHz)	6	6
Polarization	Horizontal	Horizontal
Power of TX (dBm)	60,79	64
ERP (dBm)[1]	75,92	76,15
Antenna Type	Antenna Array[2]	Directional
Antenna Gain (dBi)	15,13	12,15
Azimuth	268°	230°
Elevation Angle	3° to 4°	2°
Antenna Height (m)	100	50

Table 6. Transmitters’ parameter for channel 18.

[1] Considering losses of cables and connectors.
[2] 4 panel antennas at 0°, 90°, 180° y 270°.

Location	Field Strength (dBµV/m)			
	Rx at 2 m	Rx at 4 m	Rx at 6 m	Rx at 8 m
Bebedero	73.5	79.5	83	85.5
Ciudad Colon	-	-	-	-
Escazu	74.4	80.4	83.9	86.4
Santa Ana	64.1	65.1	66.2	67.5
Uruca	67.7	68.7	69.8	71.2
Belen	64.7	65.7	66.8	68.1
Lagunilla	74	76.5	80.1	85
Malinche	75.1	81.1	84.6	87.1
Mercedes Norte	73.4	76	79.5	84.4
Santo Domingo	68.3	69.2	70.4	71.7
Alajuela	63	64	65.1	66.4
Coyol	68.4	70.8	74.2	78.9
Garita	63.5	73.6	77.2	79.8
Poas	61	61.9	63.1	64.3
Tambor	69.9	75.9	79.4	81.9
Tibas	68.9	69.9	71	72.4
Moravia	77.3	80	83.7	88.9
Curridabat	77.7	83.7	87.2	89.7
Guadalupe	69.5	70.5	71.7	73
San Francisco	68.3	69.2	70.4	71.7
San Pedro	69.3	70.3	71.5	72.8
Vargas Araya	70.3	71.3	72.4	73.8
Hatillo	67.4	68.4	69.5	70.8
Sabana	67.6	68.6	69.7	71
San Jose	76.4	82.4	85.9	88.4
Grecia	69.4	71.9	75.2	79.9
Guacima	-	-	60.4	61.6
Puente Piedra	67.5	73.5	77	79.5
Turrucares	63.7	72.7	76.3	78.8
Barva	73.4	75.9	79.4	84.3
Heredia	75.7	81.7	85.2	87.7
San Pablo	74.4	77	80.6	85.5
Santa Barbara	64.8	65.8	66.9	68.2
Cartago	-	-	-	-
Guadalupe Cartago	71.7	74.7	78.6	84.2
Pavas	67	67.9	69.1	70.4
Rohmoser	67.5	68.5	69.6	70.9
Taras	70.8	73.8	78	83.6
Tejar	70.4	73.4	77.3	82.8
Aguacaliente	67.2	73.2	76.7	79.2
Guarco	73.6	79.6	83.1	85.6
San Rafael Oreamuno	-	-	60.1	61.5
Tobosi	74	76.8	80.6	85.9
Tres Ríos	68.8	69.9	71	72.4
Calle Blancos	69.1	70.1	71.2	72.6

Table 7. Expected Signal Level for channel 18, at the measuring locations at different heights.[3]

[3] For the case of channel 18, due to the SFN configuration and that the simulation software Chirplus BC is uncapable to deliver test point values for SFN scenarios, and only delivers a coverage representing the difference between the resulting coverage and the threshold of 60 dBµV/m, there are locations without signal level because from the coverage obtained there is no value assigned, which means that on those exact points the resulting coverage from the SFN is lower than the threshold.

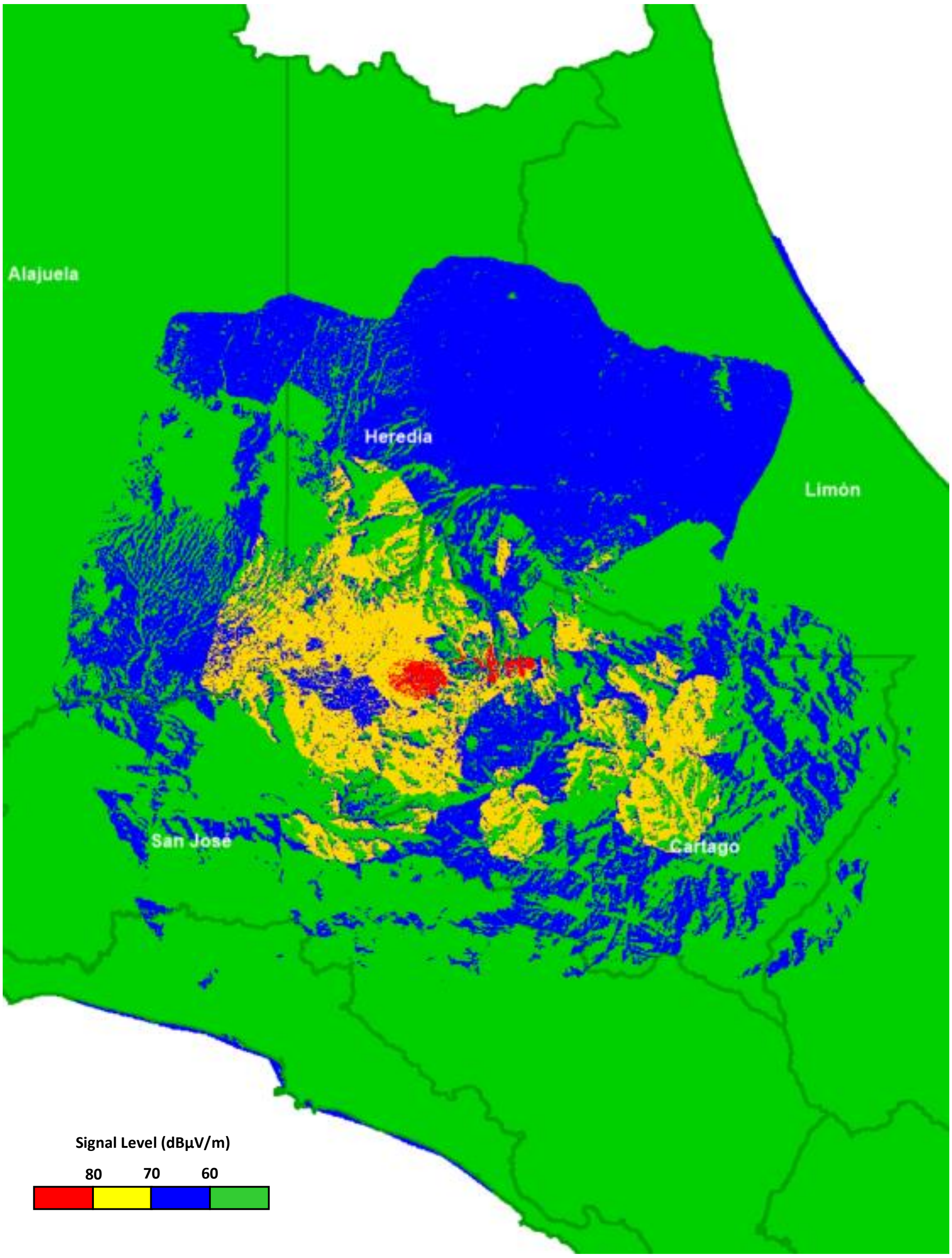

Figure 19. Channel 18 coverage simulation with receivers at a height of 2m.

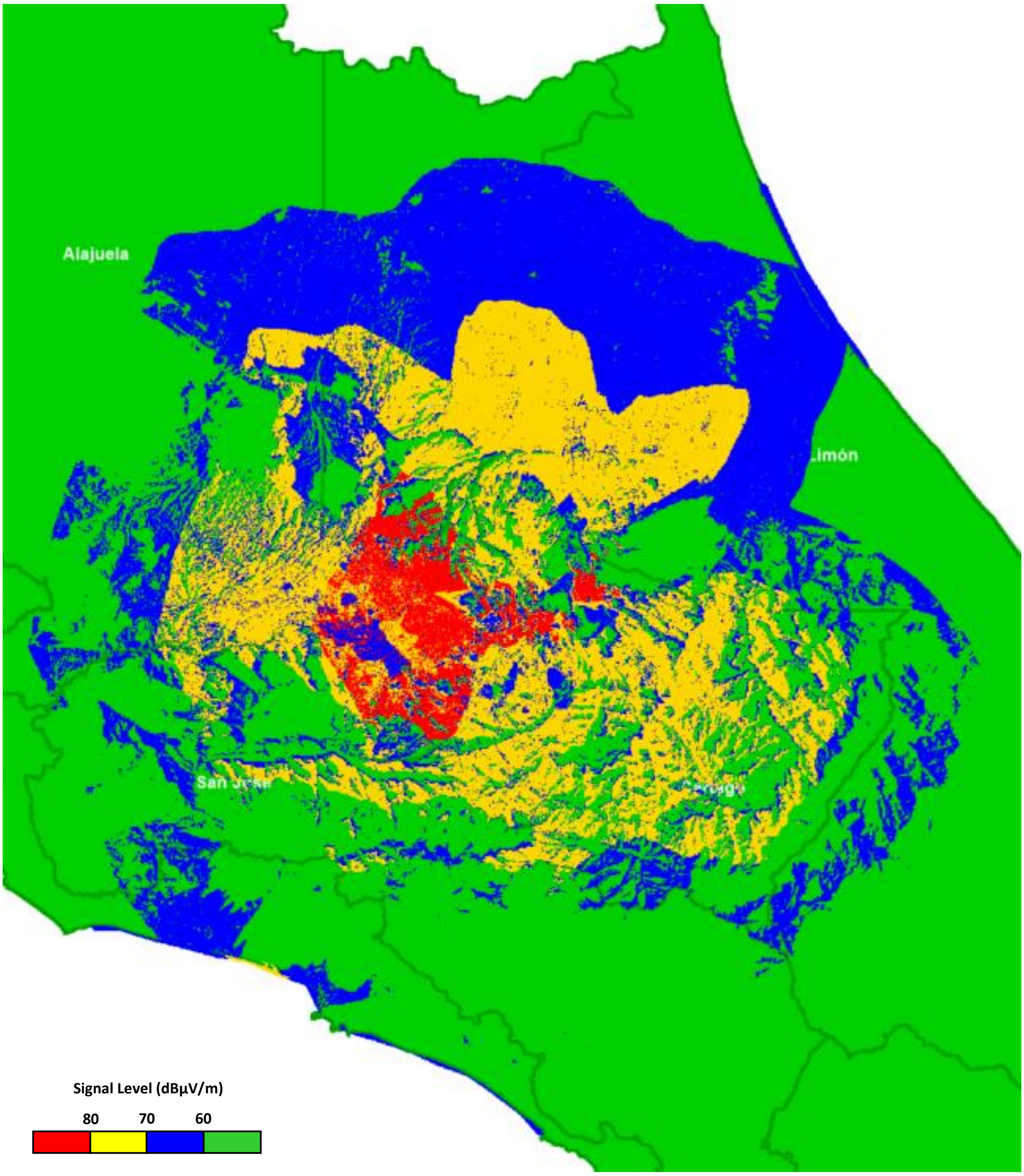

Figure 20. Channel 18 coverage simulation with receivers at a height of 4m.

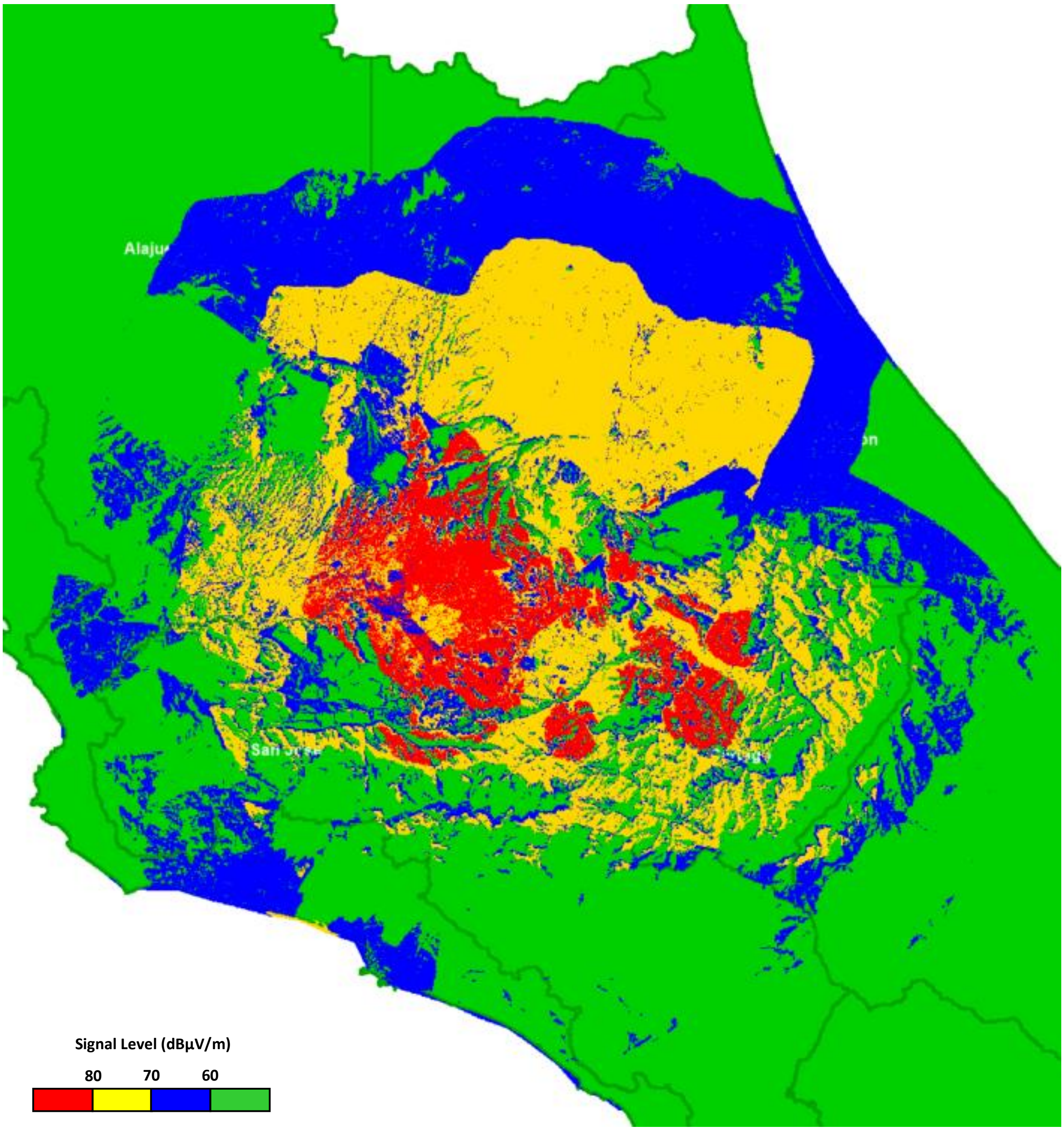

Figure 21. Channel 18 coverage simulation with receivers at a height of 6m.

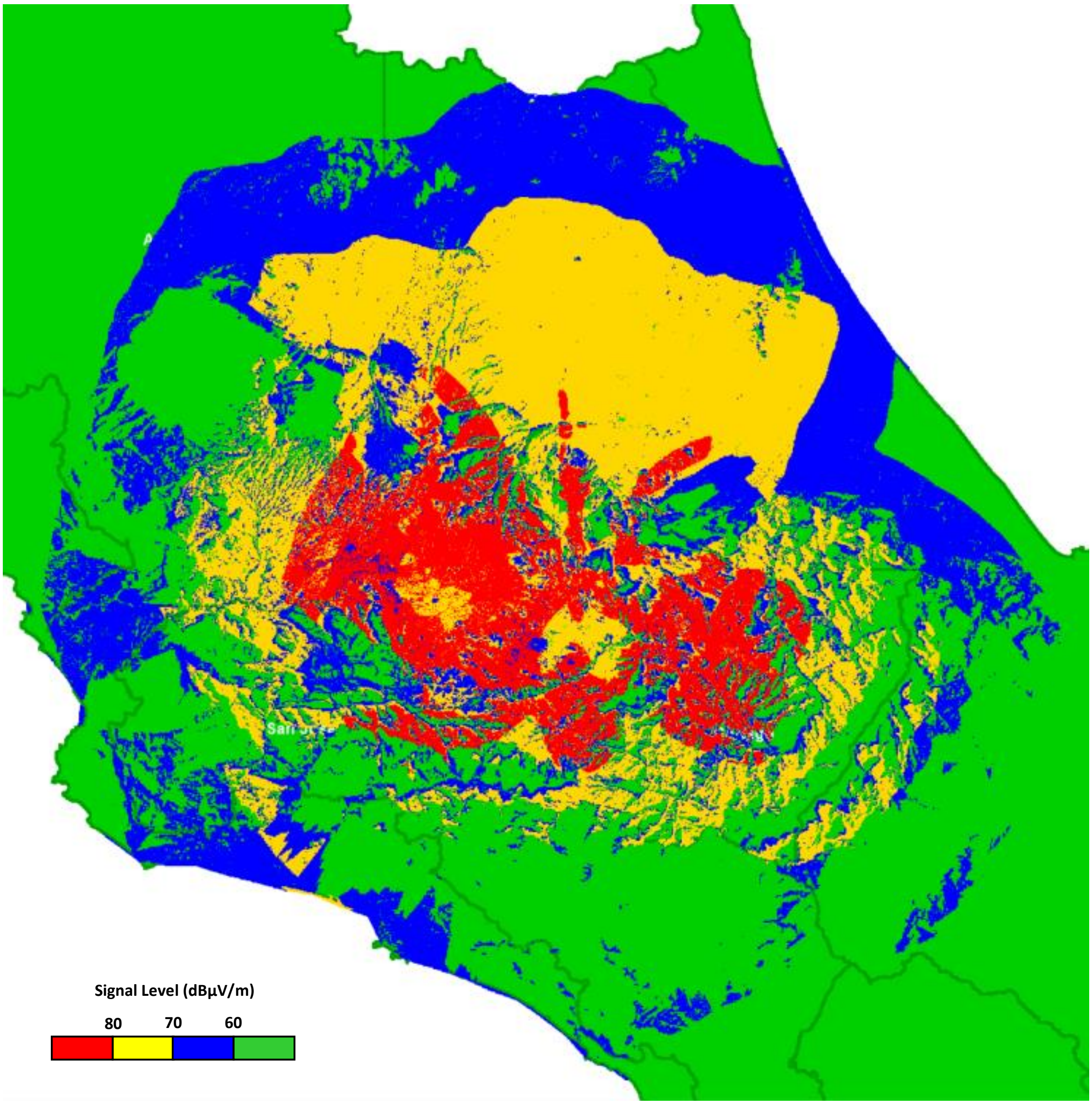

Figure 22. Channel 18 coverage simulation with receivers at a height of 8m.

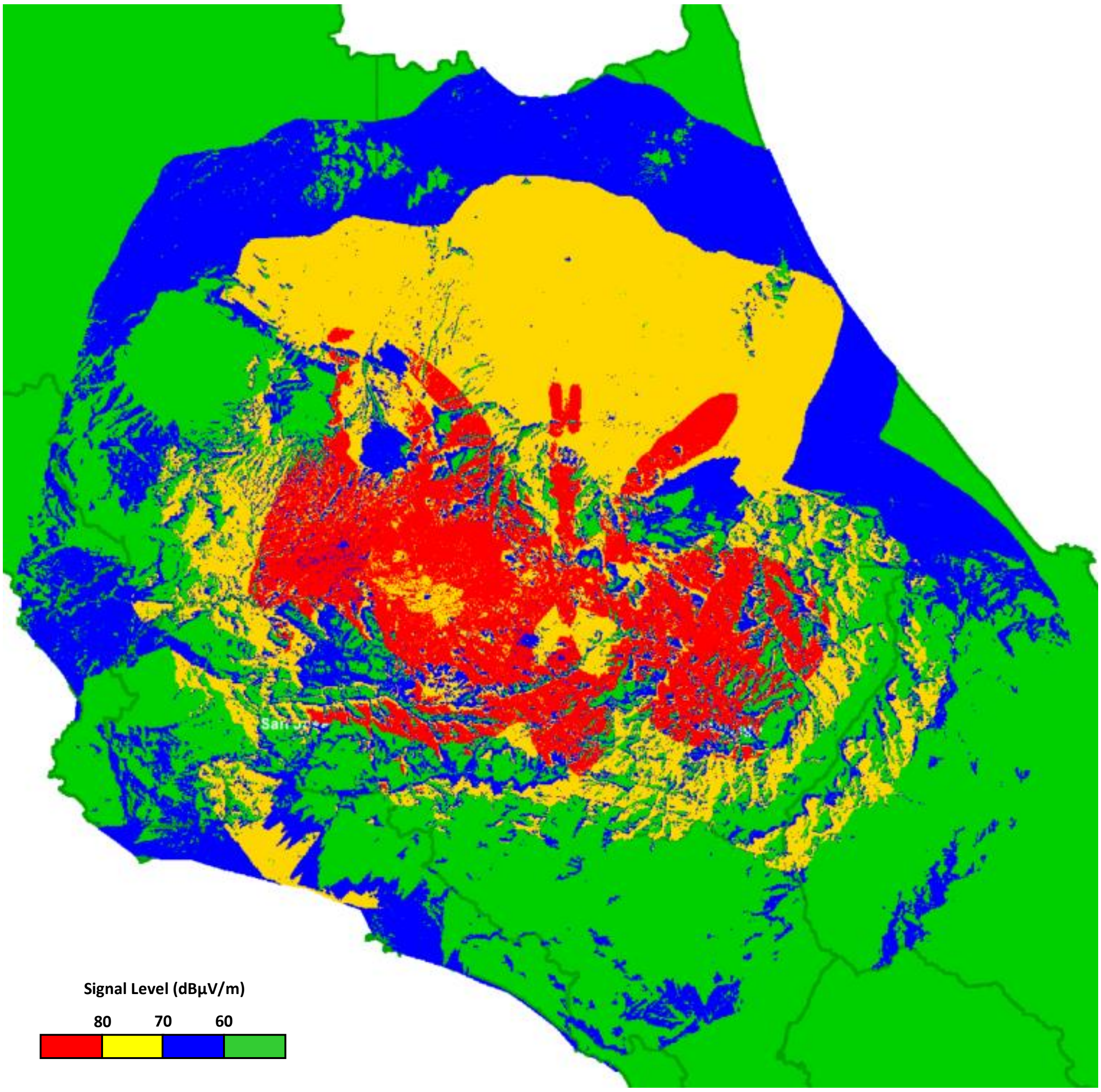

Figure 23 Channel 18 coverage simulation with receivers at a height of 10 m.

Channel 30

For the simulations of channel 30 was considered one transmitter that give coverage to the area where the measurements were performed.

PARAMETERS	TRANSMITTER 1
Name of location	Volcán Irazú
Location	Cartago, Oreamuno, Santa Rosa. North Latitude: 09°58'19,898" West Longitude: 83°51'32,101"
Digital standard	ISDB-Tb
Central frequency (MHz)	569
Bandwidth (MHz)	6
Polarization	Horizontal
Power of TX (dBm)	56,51
ERP (dBm)[4]	71,85
Antenna Type	Antenna Array[5]
Antenna Gain (dBi)	15,34
Azimuth	268°
Elevation Angle	3° to 4°
Antenna Height (m)	100

Table 8. Transmitter's parameters for channel 30.

[4] Considering losses of cables and connectors.
[5] 4 panel antennas a 0°, 90°, 180º and 270°.

Location	Field Strength (dBµV/m)			
	Rx at 2 m	Rx at 4 m	Rx at 6 m	Rx at 8 m
Bebedero	70.3	72.8	76.3	81.4
Ciudad Colon	51.9	58.1	61.8	64.4
Escazu	64.1	65.1	66.2	67.5
Santa Ana	63.1	64	65.1	66.5
Uruca	65.6	66.6	67.7	69
Belen	63.3	64.3	65.4	66.7
Lagunilla	74	80.2	83.7	86.3
Malinche	73.7	79.8	83.3	85.9
Mercedes Norte	71.7	74.3	77.9	83
Santo Domingo	66	66.9	68.1	69.4
Alajuela	68.5	71	74.5	79.5
Coyol	69.1	75.2	78.8	81.3
Garita	62.8	73.1	76.8	79.4
Poas	68.4	74.5	78.1	80.6
Tambor	69	75.1	78.7	81.2
Tibas	66.3	67.2	68.4	69.7
Moravia	66.6	67.6	68.8	70.2
Curridabat	64.7	65.7	66.8	68.2
Guadalupe	66.2	67.2	68.4	69.7
San Francisco	64.8	65.8	67	68.3
San Pedro	65.8	66.8	68	69.3
Vargas Araya	65.7	66.7	67.8	69.2
Hatillo	64.9	65.8	67	68.3
Sabana	65.3	66.3	67.4	68.7
San Jose	74.5	80.6	84.1	86.7
Grecia	65.7	71.8	75.4	77.9
Guacima	68.1	70.6	74	79
Puente Piedra	66.6	72.7	76.3	78.8
Turrucares	46.4	50.2	55.2	61.9
Barva	71.6	74.2	77.7	82.9
Heredia	74.1	80.2	83.8	86.3
San Pablo	72.4	75	78.7	83.8
Santa Barbara	72.2	78.3	81.9	84.4
Cartago	52.4	53	53.6	54.4
Guadalupe Cartago	68.4	71.4	75.6	81.5
Pavas	65	66	67.1	68.5
Rohmoser	65.3	66.3	67.4	68.7
Taras	67.7	70.7	75	81
Tejar	66.1	69	73.2	79
Aguacaliente	60.3	66.5	70.1	72.6
Guarco	70.8	76.9	80.5	83
San Rafael Oreamuno	51.5	52.6	53.8	55.3
Tobosi	72.9	75.7	79.6	85.2
Tres Ríos	62.8	63.9	65.1	66.5
Calle Blancos	66.3	67.3	68.4	69.8

Table 9. Expected Signal Level for channel 30, at the measuring locations at different heights.

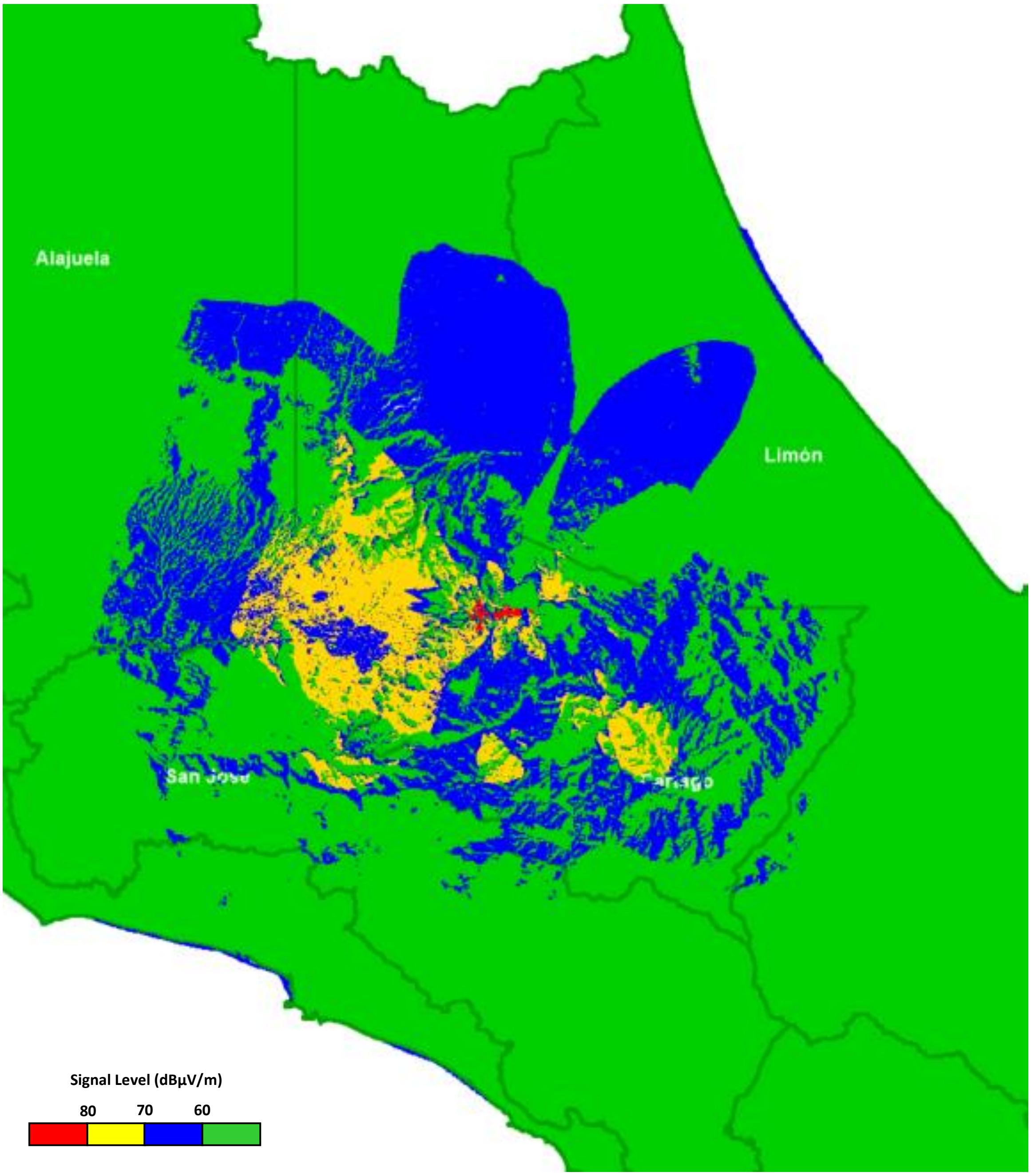

Figure 24. Channel 30 coverage simulation with receivers at a height of 2m.

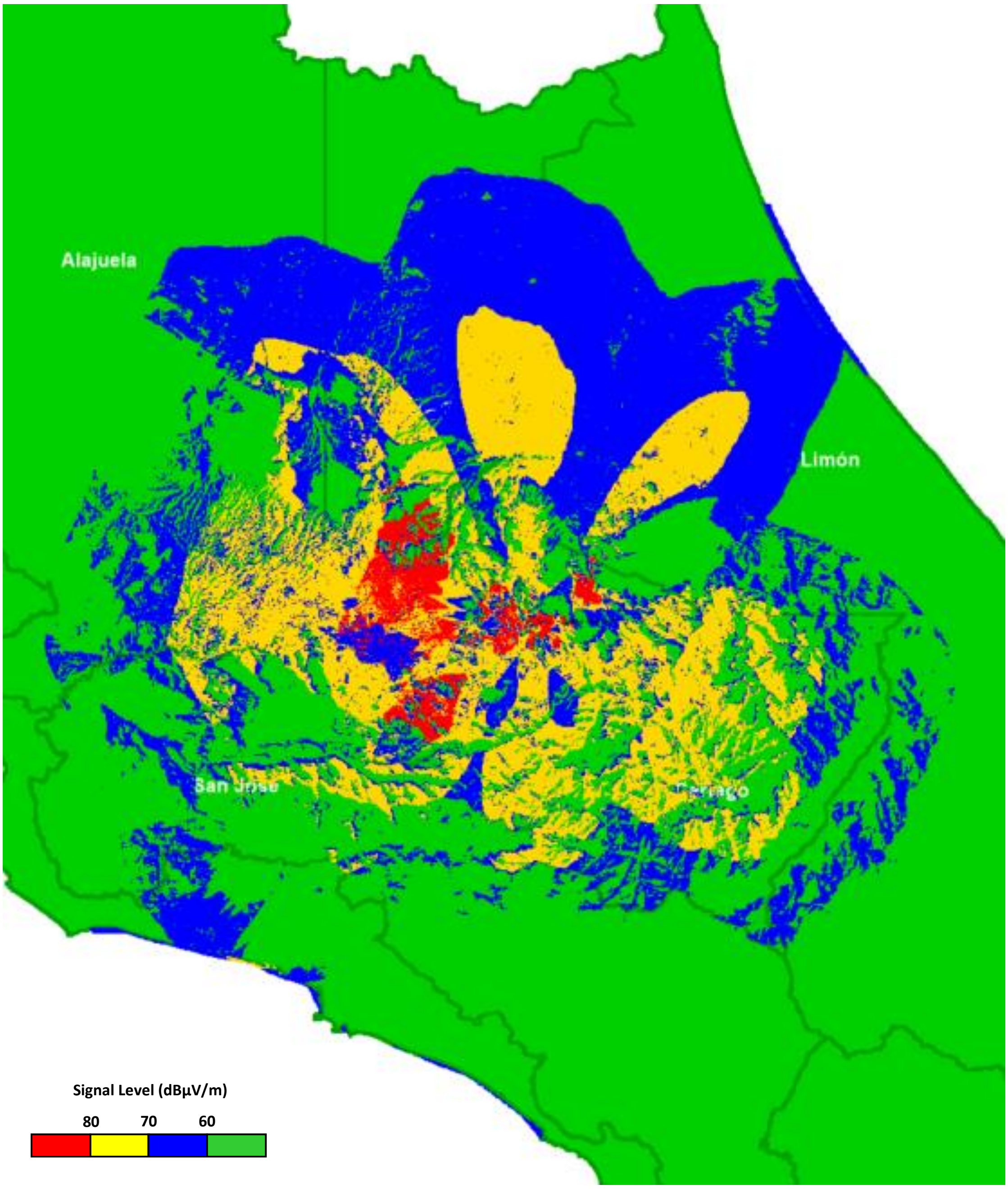

Figure 25. Channel 30 coverage simulation with receivers at a height of 4m.

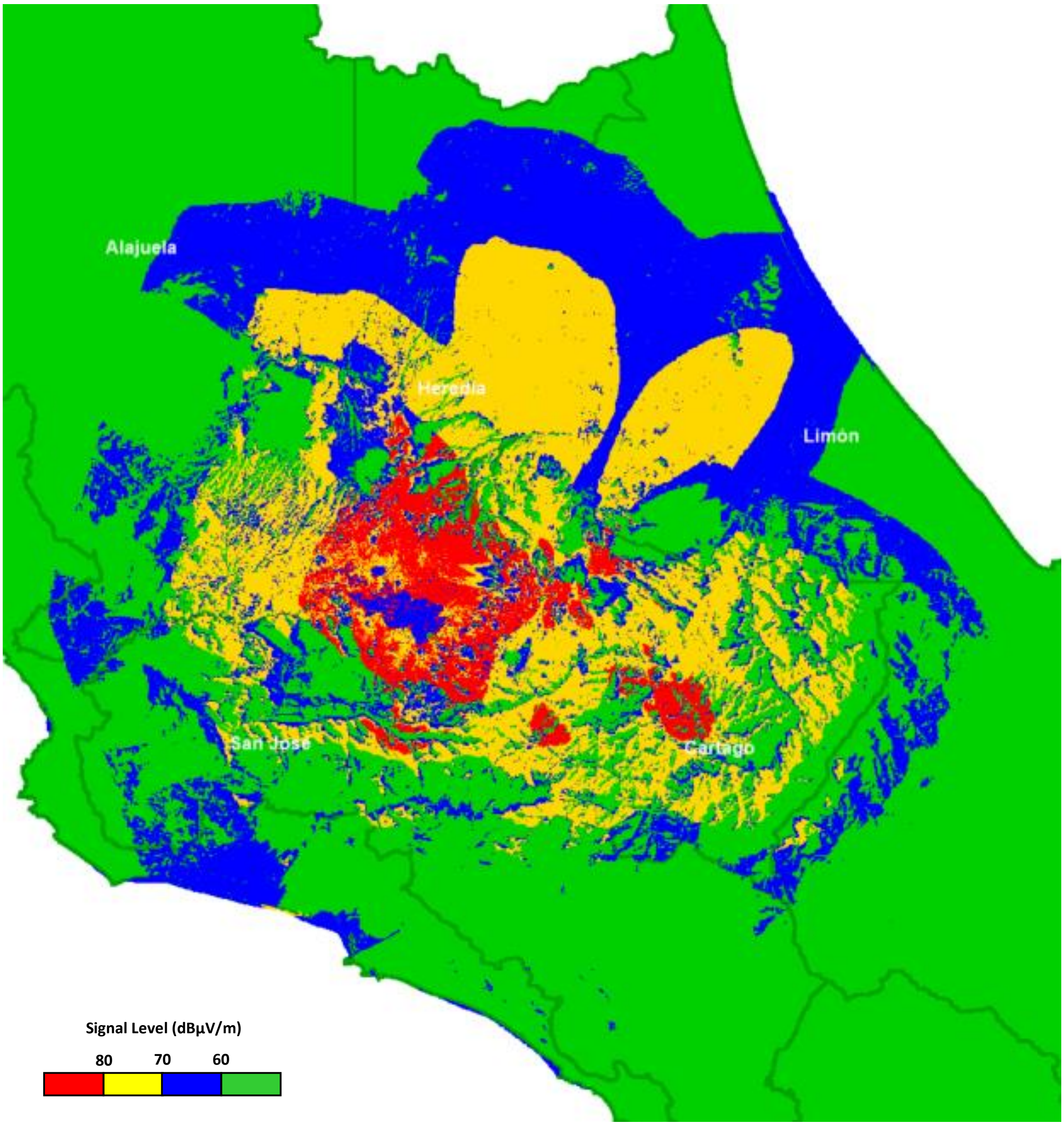

Figure 26. Channel 30 coverage simulation with receivers at a height of 6m.

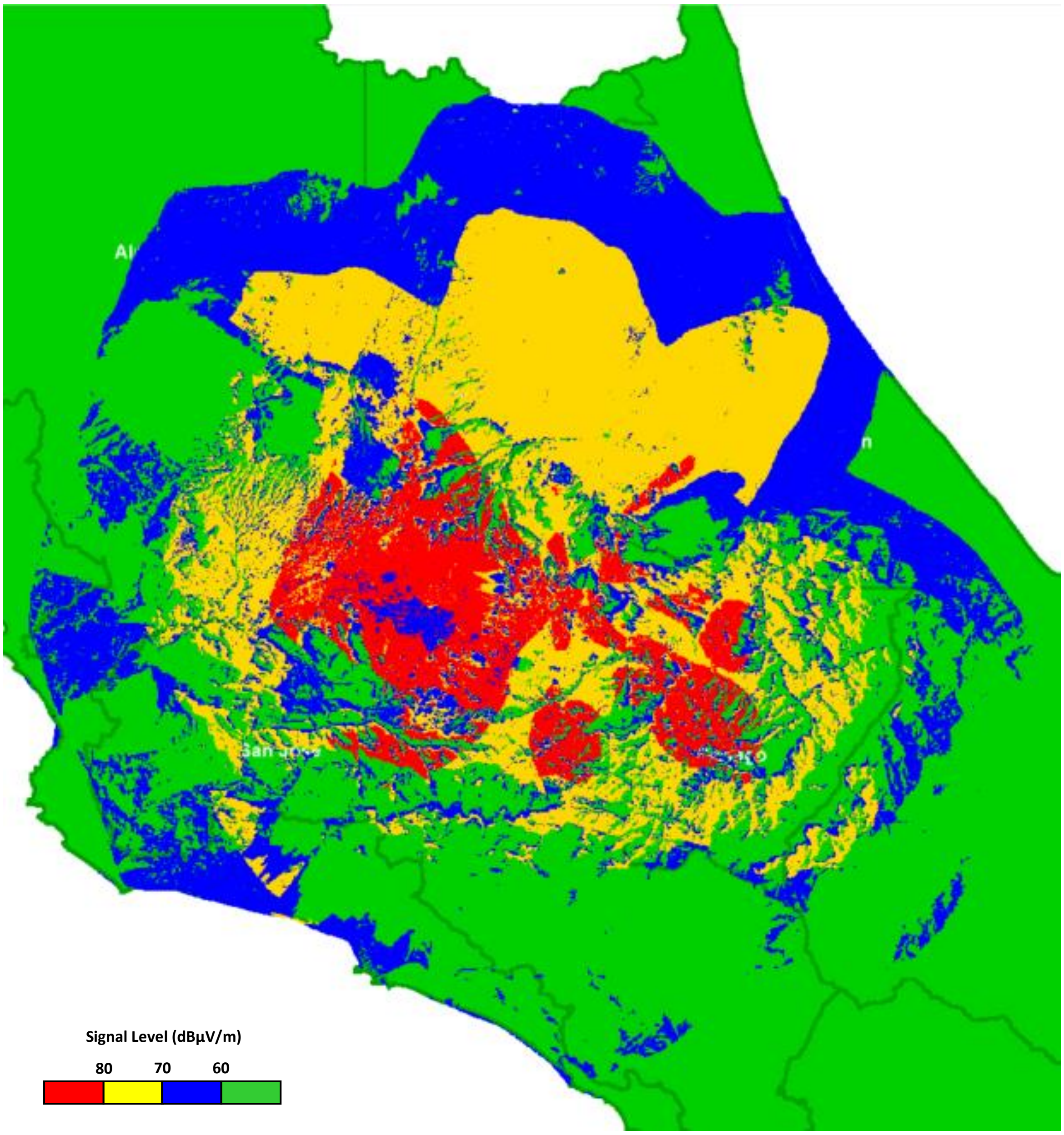

Figure 27. Channel 30 coverage simulation with receivers at a height of 8m.

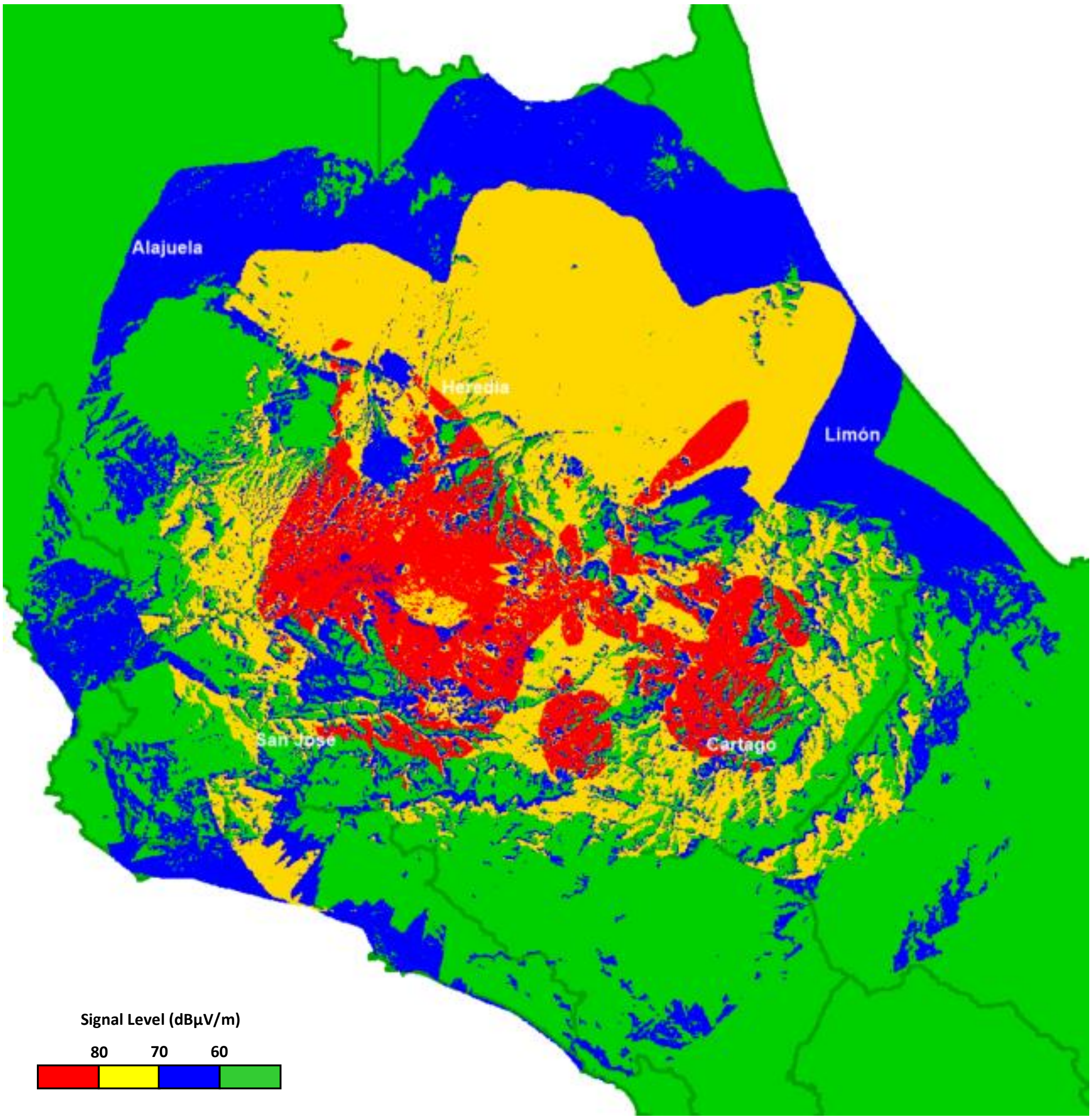

Figure 28. Channel 30 coverage simulation with receivers at a height of 10m.

Channel 49

For the simulations of channel 30 was considered one transmitter that give coverage to the area where the measurements were performed.

PARAMETERS	TRANSMITTER 1
Name of location	Volcán Irazú
Location	Cartago, Oreamuno, Santa Rosa. North Latitude: 09°58'20,37" West Longitude: 83°51'45,14"
Digital standard	ISDB-Tb
Central frequency (MHz)	683
Bandwidth (MHz)	6
Polarization	Horizontal
Power of TX (dBm)	53
ERP (dBm)[6]	70,87
Antenna Type	Antenna Array[7]
Antenna Gain (dBi)	17,87
Azimuth	270°
Elevation Angle	3° to 4°
Antenna Height (m)	35

Table 10. Transmitter's parameters for channel 49.

[6] Considering losses of cables and connectors.
[7] 4 panel antennas a 270°, 2 at 0° and 2 at 190°.

Location	Field Strength (dBµV/m)			
	Rx at 2 m	Rx at 4 m	Rx at 6 m	Rx at 8 m
Bebedero	67.7	70.2	73.8	79.2
Ciudad Colon	49.8	56.1	59.8	62.5
Escazu	62.5	63.5	64.6	65.9
Santa Ana	61.3	62.3	63.4	64.7
Uruca	64.3	65.2	66.4	67.7
Belen	61.7	62.6	63.8	65.1
Lagunilla	73.1	79.4	83	85.6
Malinche	72.5	78.7	82.4	85
Mercedes Norte	70.3	72.9	76.6	82
Santo Domingo	64.8	65.7	66.9	68.2
Alajuela	66.5	69.1	72.6	77.9
Coyol	67.4	73.7	77.3	79.9
Garita	60.2	70.7	75.1	77.7
Poas	66.4	72.6	76.3	78.9
Tambor	67.3	73.5	77.2	79.8
Tibas	65	66	67.1	68.5
Moravia	65.4	66.4	67.6	69
Curridabat	63	64	65.1	66.5
Guadalupe	64.9	65.9	67	68.4
San Francisco	63.1	64.1	65.3	66.6
San Pedro	64.4	65.4	66.5	67.9
Vargas Araya	64	65	66.2	67.6
Hatillo	63.3	64.3	65.4	66.8
Sabana	63.6	64.6	65.8	67.1
San Jose	73.4	79.6	83.3	85.9
Grecia	63.6	69.8	73.5	76.1
Guacima	66.1	68.6	72.2	77.4
Puente Piedra	64.6	70.9	74.5	77.1
Turrucares	43.7	47.5	52.5	59.5
Barva	70.1	72.7	76.4	81.8
Heredia	73.1	79.3	83	85.6
San Pablo	71.1	73.7	77.4	82.9
Santa Barbara	71	77.2	80.9	83.5
Cartago	51.6	52.2	52.9	53.7
Guadalupe Cartago	67.4	70.4	74.7	81.1
Pavas	63.5	64.5	65.6	66.9
Rohmoser	63.8	64.8	65.9	67.3
Taras	63.5	66.6	71	77.5
Tejar	67.3	70.2	74.5	80.7
Aguacaliente	64.2	70.5	74.2	76.9
Guarco	71.6	77.8	81.5	84.1
San Rafael Oreamuno	50	51.1	52.4	53.9
Tobosi	70.7	73.6	77.5	83.5
Tres Ríos	58.7	59.8	61	62.5
Calle Blancos	64.9	65.9	67	68.4

Table 11. Expected Signal Level for channel 49, at the measuring locations at different heights.

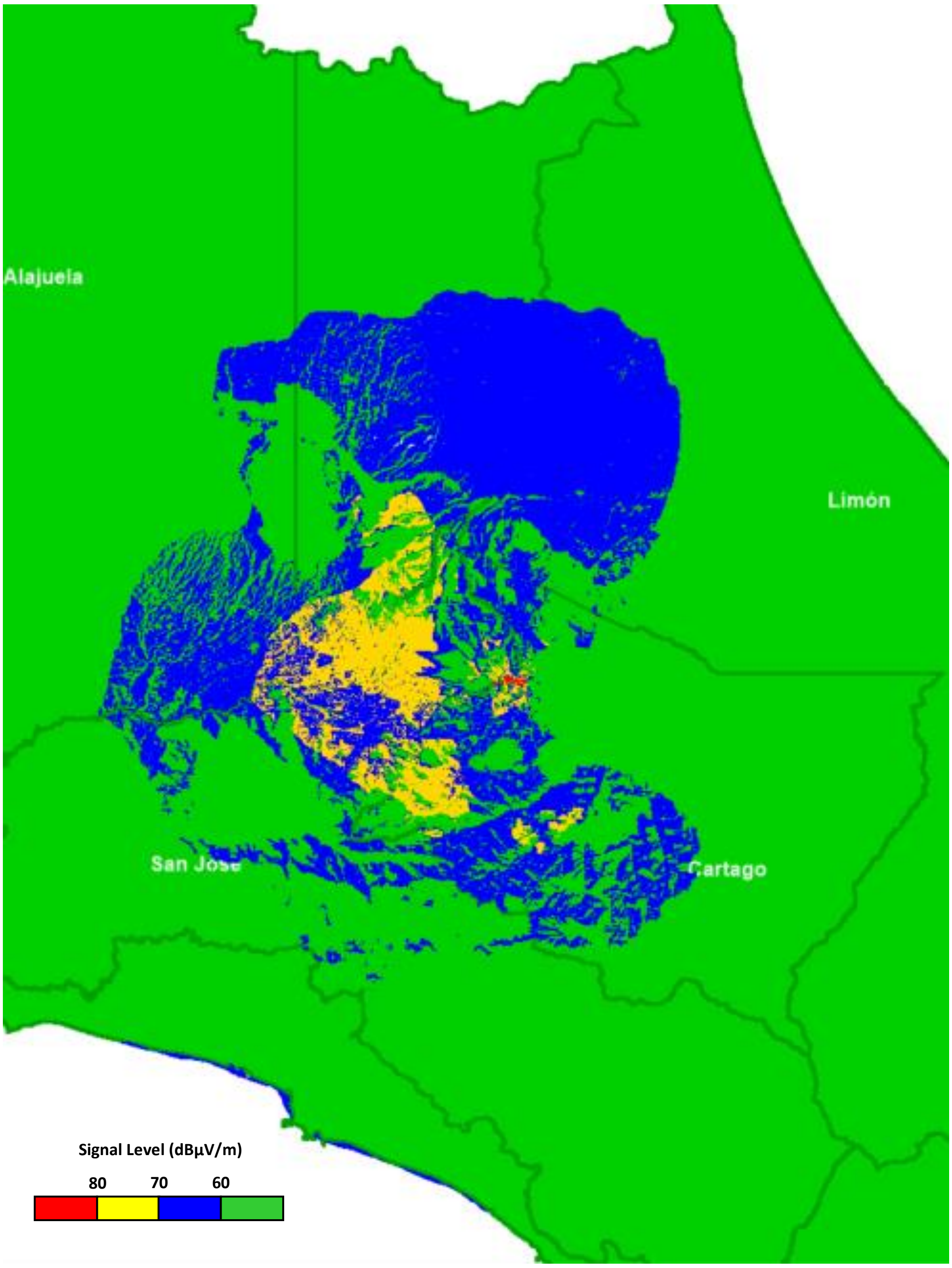

Figure 29. Channel 49 coverage simulation with receivers at a height of 2m.

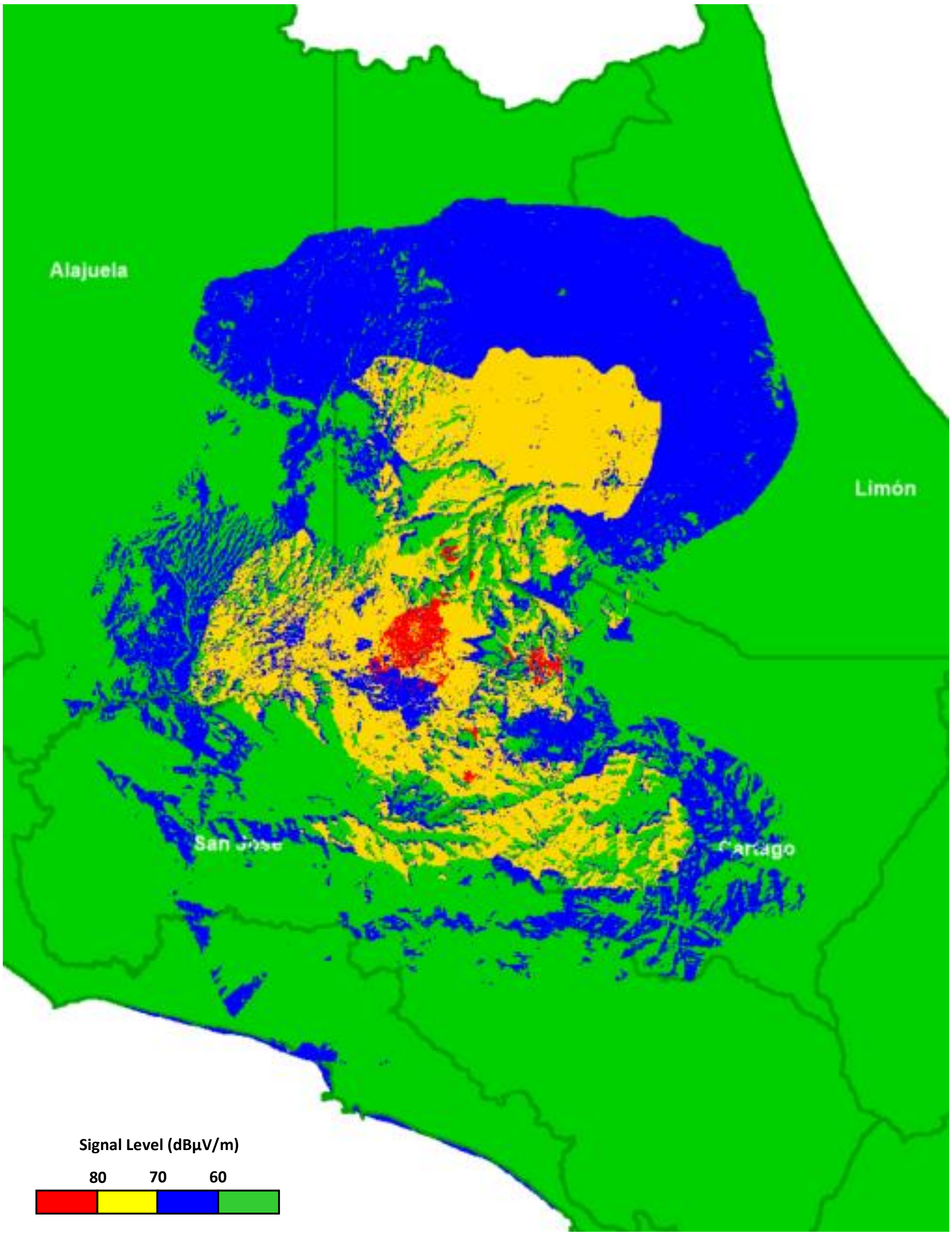

Figure 30. Channel 49 coverage simulation with receivers at a height of 4m.

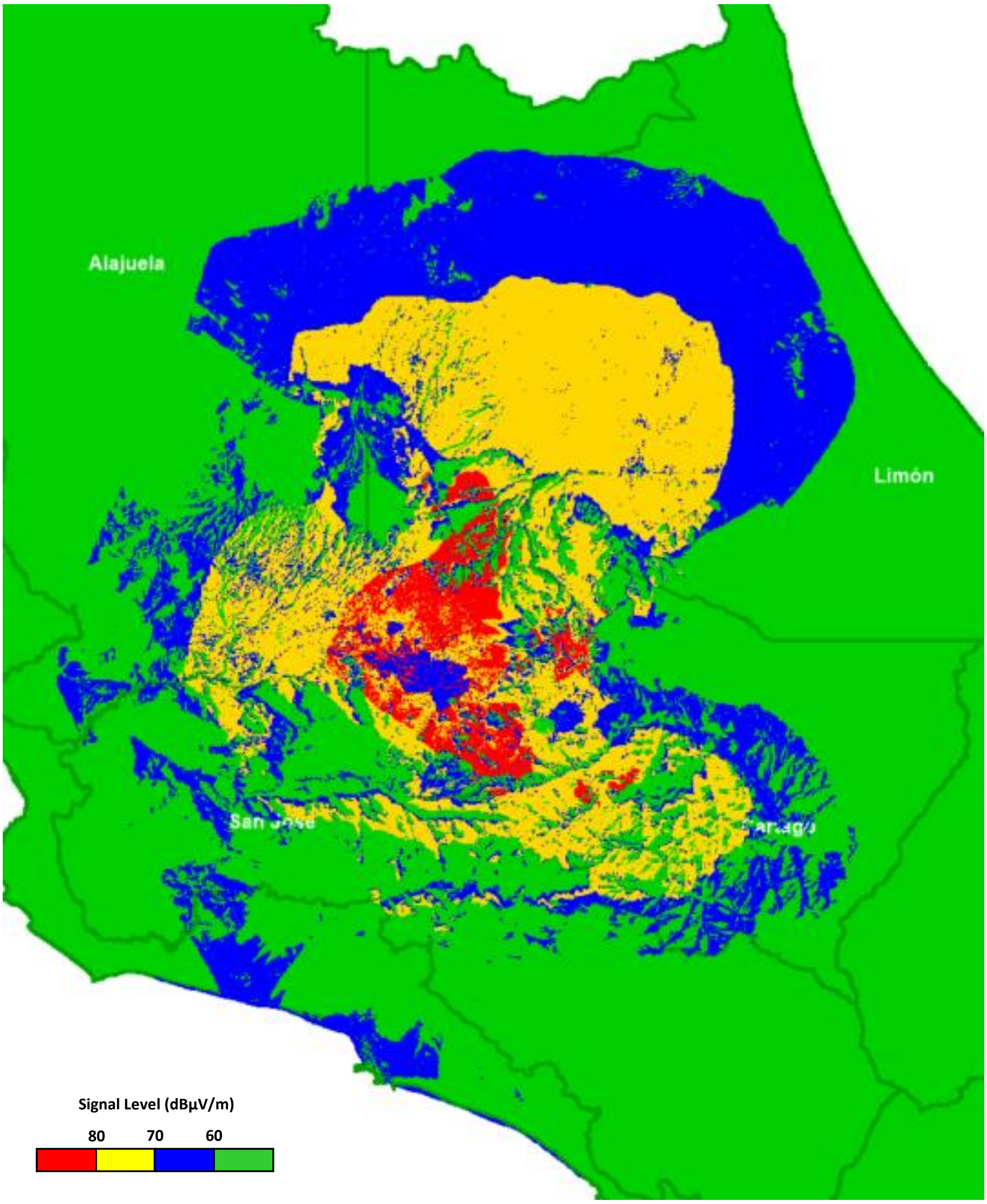

Figure 31. Channel 49 coverage simulation with receivers at a height of 6m.

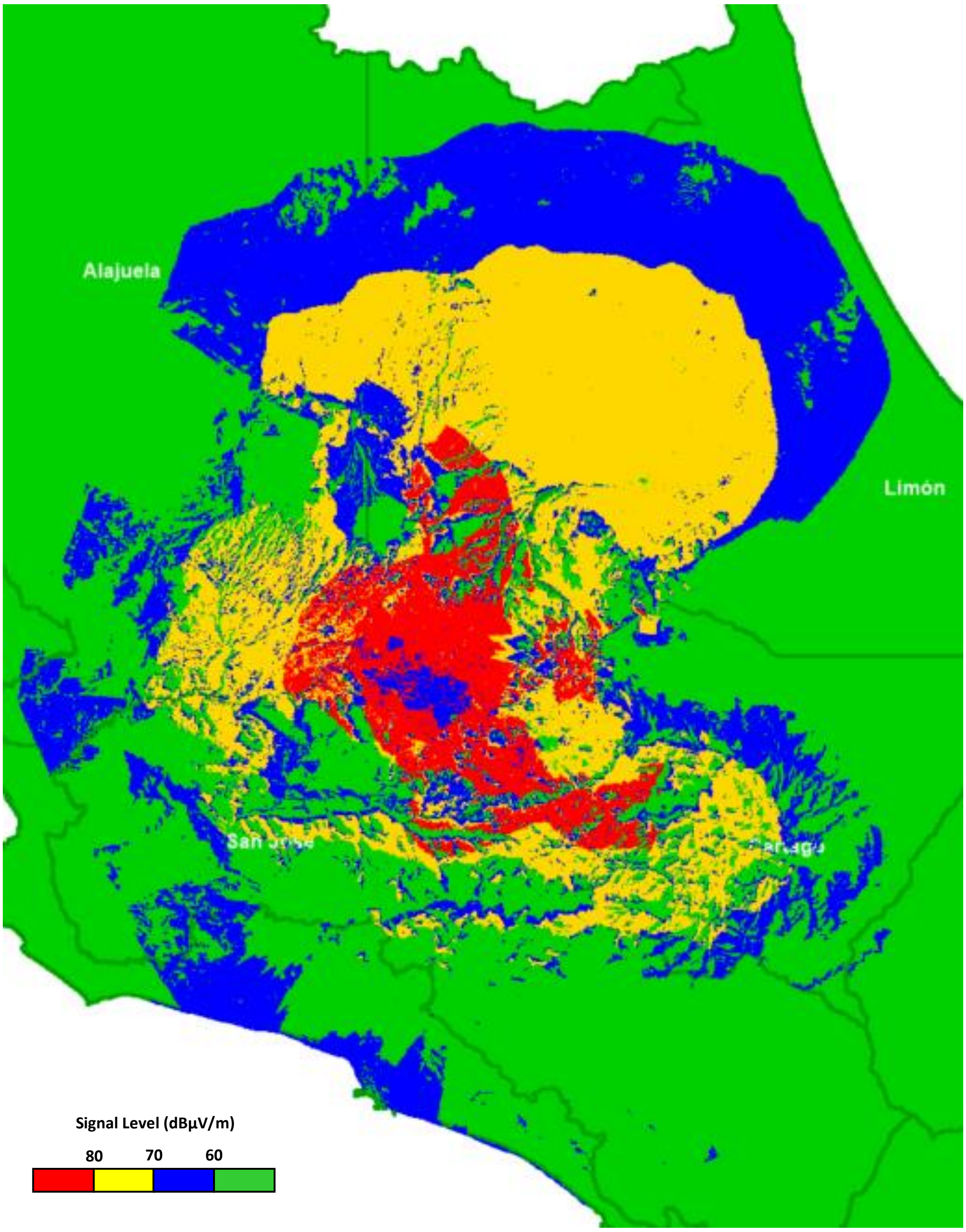

Figure 32. Channel 49 coverage simulation with receivers at a height of 8m.

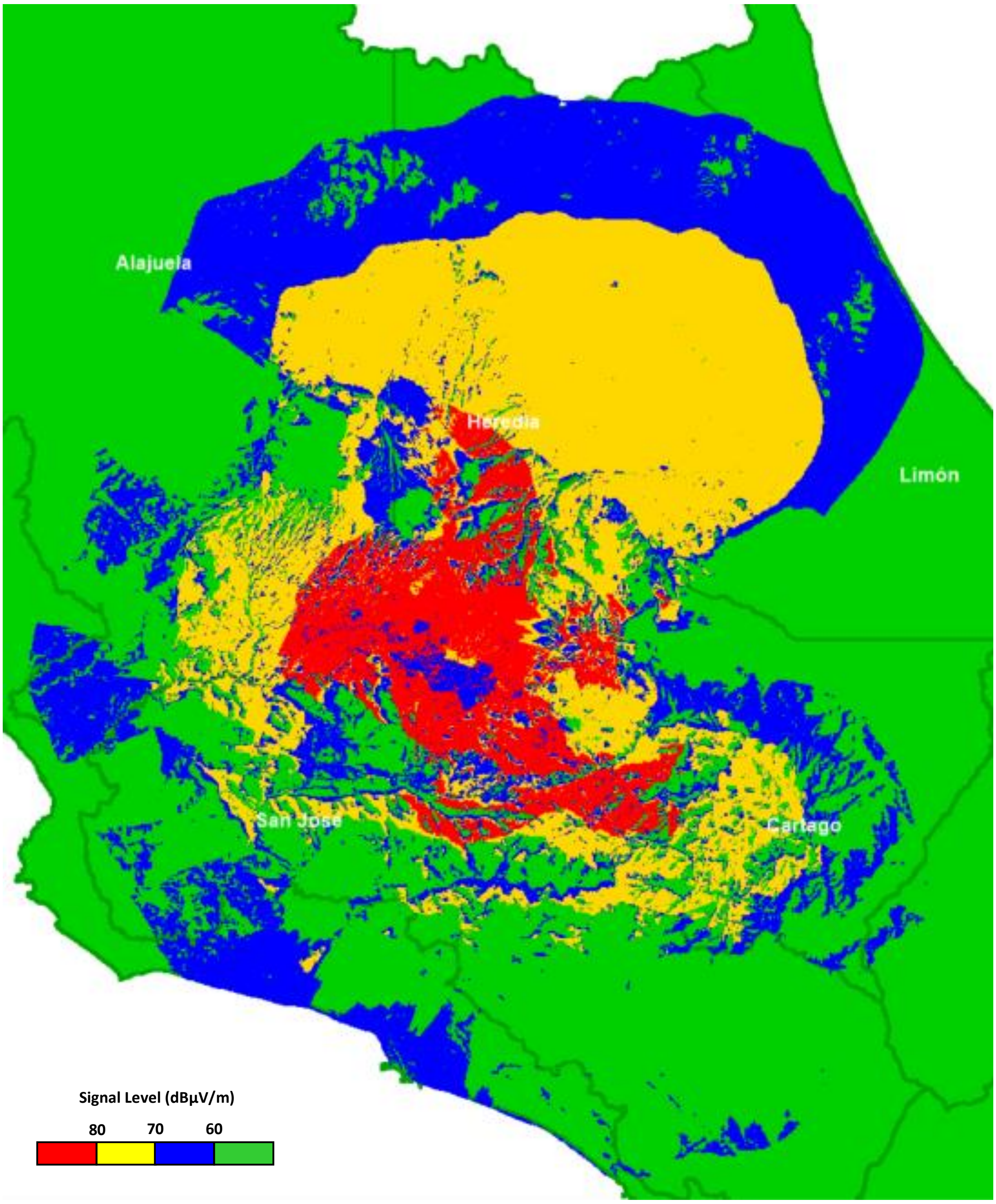

Figure 33. Channel 49 coverage simulation with receivers at a height of 10m.

Appendix 2. Measurements

In this section will be displayed all the measurement results obtained for the field tests performed for the channels at different heights. In Table 12 can be observed a fragment of the measurement results delivered by the ETL analyzer, then are present the summary of all the results obtained for each channel at the different heights considering the average value for signal level and MER obtained at each location.

Time	10:47:22	10:47:28	10:47:34	10:47:39	10:47:45
Frequency (Hz)	497142857	497142857	497142857	497142857	497142857
ISDB-T Level (dBµV/m)	81	80.6	81	80.9	81.1
ISDB-T Mode	MODE 3 (8K)	MODE 3 (8K)	MODE 3 (8K)	MODE 3 (8K)	MODE 3 (8K)
ISDB-T Guard Interval	1/4	1/4	1/4	1/4	1/4
ISDB-T Bit Rate Offs_ (ppm)	0.24	0.24	0.23	0.23	0.23
ISDB-T MER (RMS) (dB)	32.294	32.842	32.636	32.66	33.355
ISDB-T MER (Peak) (dB)	-0.028	2.112	0.764	1.757	5.397
ISDB-T MER (TMCC) (dB)	34.8	35.3	35.4	35.4	35.7
ISDB-T MER (AC) (dB)	34.8	35.2	35.3	34.7	35.3
ISDB-T Quadr_Err (Grad)	-0.07	-0.11	-0.07	-0.09	-0.11
ISDB-T System ID	ISDB-T	ISDB-T	ISDB-T	ISDB-T	ISDB-T
ISDB-T Modulation Layer A	QPSK	QPSK	QPSK	QPSK	QPSK
ISDB-T Modulation Layer B	QAM64	QAM64	QAM64	QAM64	QAM64
ISDB-T Modulation Layer C	n/a	n/a	n/a	n/a	n/a
ISDB-T Code Rate Layer A	2/3	2/3	2/3	2/3	2/3
ISDB-T Code Rate Layer B	3/4	3/4	3/4	3/4	3/4
ISDB-T Code Rate Layer C	n/a	n/a	n/a	n/a	n/a
ISDB-T Time Interl_ Layer A	4	4	4	4	4
ISDB-T Time Interl_ Layer B	4	4	4	4	4
ISDB-T Time Interl_ Layer C	n/a	n/a	n/a	n/a	n/a
ISDB-T Nr_ of Segm_ Layer A	1	1	1	1	1
ISDB-T Nr_ of Segm_ Layer B	12	12	12	12	12
ISDB-T Nr_ of Segm_ Layer C	*	*	*	*	*
ISDB-T MER (RMS) Layer A (dB)	27.1	27.6	27.8	28.6	31
ISDB-T MER (RMS) Layer B (dB)	32.6	32.8	32.8	33.2	33
ISDB-T MER (RMS) Layer C (dB)	-1E+40	-1E+40	-1E+40	-1E+40	-1E+40
ISDB-T MER (Peak) Layer A (dB)	0.3	0.9	1.1	2.2	6.1
ISDB-T MER (Peak) Layer B (dB)	14.7	15	11.9	17.4	16.3
ISDB-T MER (Peak) Layer C (dB)	-1E+40	-1E+40	-1E+40	-1E+40	-1E+40
ISDB-T BER bef_ VIT Layer A ()	0.00014	0.000063	0.000009	0	0
ISDB-T BER bef_ VIT Layer B ()	0.000039	0.0000001	0.0000043	0.0000028	0.000011
ISDB-T BER bef_ VIT Layer C ()	-1E+40	-1E+40	-1E+40	-1E+40	-1E+40
ISDB-T BER before RS Layer A ()	0	0	0	0	0
ISDB-T BER before RS Layer B ()	0	0	0	0	0
ISDB-T BER before RS Layer C ()	-1E+40	-1E+40	-1E+40	-1E+40	-1E+40
ISDB-T BER after RS Layer A ()	0	0	0	0	0
ISDB-T BER after RS Layer B ()	0	0	0	0	0
ISDB-T BER after RS Layer C ()	-1E+40	-1E+40	-1E+40	-1E+40	-1E+40
ISDB-T Packet Err Rate Layer A ()	0	0	0	0	0
ISDB-T Packet Err Rate Layer B ()	0	0	0	0	0
ISDB-T Packet Err Rate Layer C ()	-1E+40	-1E+40	-1E+40	-1E+40	-1E+40
ISDB-T Packet Errors Layer A (/s)	0	0	0	0	0
ISDB-T Packet Errors Layer B (/s)	0	0	0	0	0
ISDB-T Packet Errors Layer C (/s)	-1E+40	-1E+40	-1E+40	-1E+40	-1E+40
ISDB-T MPEG Ts Bitr_ Layer A (MBits/s)	0.374479	0.374479	0.374479	0.374479	0.374479
ISDB-T MPEG Ts Bitr_ Layer B (MBits/s)	15.16639	15.16639	15.16639	15.16639	15.16639
ISDB-T MPEG Ts Bitr_ Layer C (MBits/s)	-1E+40	-1E+40	-1E+40	-1E+40	-1E+40

Table 12. Fragment of ETL's measurement results for channel 18 at site Malinche at 2 m.[8]

[8] The value -1E+40 indicates a null, beacuse no result was obtained.

Channel 18

Location	Intensidad (dBuV/m)				MER (dB)			
	2m	4m	6m	8m	2m	4m	6m	8m
Bebedero	72.350	76.750	79.947	81.214	16.449	18.478	N/A	7.876
Ciudad Colon	43.407	39.979	41.489	44.600	9.479	5.716	10.577	N/A
Escazu	76.171	68.865	79.367	74.279	29.712	25.260	30.971	24.989
Santa Ana	57.514	57.327	55.879	55.971	21.052	21.600	18.396	19.803
Uruca	69.114	71.086	72.877	71.786	22.669	26.701	24.429	22.738
Belen	65.594	65.879	68.279	71.700	25.177	20.537	24.793	26.083
Lagunilla	78.967	79.600	71.586	78.160	29.681	26.529	27.330	25.881
Malinche	81.107	75.805	83.007	79.900	32.520	29.506	18.343	18.788
Mercedes Norte	64.043	65.736	72.807	74.793	24.351	23.497	27.374	24.630
Santo Domingo	66.321	66.086	71.593	75.680	25.957	27.750	26.409	26.925
Alajuela	67.533	71.111	72.418	77.792	27.390	25.108	29.041	26.997
Coyol	57.379	57.027	56.390	66.885	19.911	19.704	17.265	22.721
Garita	59.650	56.931	57.375	60.433	18.459	18.181	21.209	21.712
Poas	55.300	58.300	62.908	70.250	19.517	22.415	19.417	21.036
Tambor	68.221	67.664	71.729	72.386	28.518	24.669	28.641	23.640
Tibas	74.392	76.818	78.956	80.772	28.295	26.603	27.677	24.971
Moravia	95.509	82.269	88.000	82.646	32.543	24.726	26.381	22.941
Curridabat	69.538	72.973	70.731	76.040	26.704	27.980	26.455	28.191
Guadalupe	88.150	86.014	84.369	89.172	33.444	30.754	30.268	32.525
San Francisco	79.788	82.864	78.944	80.700	30.757	32.378	27.055	27.493
San Pedro	77.000	77.887	81.780	84.827	27.636	29.466	31.780	31.883
Vargas Araya	82.728	82.008	86.817	83.047	30.901	30.724	32.072	31.037
Hatillo	75.150	76.375	78.094	78.259	21.288	25.675	23.159	23.233
Sabana	74.907	69.888	78.580	78.820	28.383	26.179	28.263	32.620
San Jose	71.513	75.814	72.487	76.607	27.839	30.479	28.029	30.622
Grecia	62.200	64.207	68.364	65.033	21.651	23.315	28.824	23.045
Guacima	64.713	61.871	69.956	68.953	24.114	20.323	25.150	26.661
Puente Piedra	69.600	65.025	66.193	66.207	28.588	24.497	24.268	24.414
Turrucares	50.086	48.800	51.943	52.293	15.530	15.201	15.478	16.076
Barva	54.787	60.721	67.543	66.007	18.130	21.623	26.941	24.377
Heredia	60.840	60.929	61.764	68.447	18.101	21.338	19.353	24.223
San Pablo	48.974	56.773	56.850	64.629	15.129	22.746	18.627	22.505
Santa Barbara	59.594	64.643	64.194	70.420	22.585	28.463	27.725	32.037
Cartago	66.764	68.629	73.247	76.550	25.834	22.008	22.464	22.911
Guadalupe Car.	74.714	70.894	67.364	71.207	29.988	26.658	21.606	20.141
Pavas	72.356	69.693	74.195	71.807	29.181	27.348	26.354	21.018
Rohmoser	72.021	67.407	73.643	73.864	26.143	27.400	29.340	27.144
Taras	69.485	74.571	75.507	78.125	27.829	15.387	N/A	N/A
Tejar	69.250	72.629	70.663	72.427	25.663	18.785	22.246	N/A
Aguacaliente	68.636	64.664	73.457	71.000	30.429	22.610	31.179	24.637
Guarco	73.721	72.014	72.036	77.786	27.607	N/A	11.018	N/A
S. Raf. Oream.	71.727	70.686	70.121	68.029	29.783	13.568	N/A	N/A
Tobosi	72.089	71.307	73.685	73.971	29.843	23.664	17.959	N/A
Tres Ríos	75.886	74.086	74.300	69.757	17.495	26.183	30.170	22.039
Calle Blancos	80.160	79.414	74.908	82.564	32.438	28.494	28.192	30.212

Table 13. Field Test results for channel 18.

Channel 30

Location	Intensidad (dBuV/m)				MER (dB)			
	2m	4m	6m	8m	2m	4m	6m	8m
Bebedero	63.494	70.171	74.313	76.400	N/A	N/A	N/A	N/A
Ciudad Colon	36.615	36.947	39.036	41.079	N/A	N/A	N/A	N/A
Escazu	59.435	69.857	67.893	72.329	18.487	26.684	25.450	26.148
Santa Ana	47.850	49.281	50.521	52.886	14.339	15.162	14.996	17.505
Uruca	50.147	56.347	59.207	56.529	12.046	16.710	21.399	17.858
Belen	54.236	56.514	57.286	59.653	15.345	17.850	13.967	13.472
Lagunilla	59.350	64.300	62.440	68.957	20.650	23.282	23.817	26.587
Malinche	63.450	68.171	75.040	75.586	22.901	23.751	18.374	21.761
Mercedes Norte	53.100	62.560	62.250	70.719	17.400	24.056	21.658	27.737
Santo Domingo	51.127	48.800	51.514	55.971	16.513	12.743	13.951	11.771
Alajuela	58.722	64.973	70.515	76.008	18.907	24.105	30.304	30.753
Coyol	48.508	51.140	56.081	60.692	13.967	15.041	18.155	23.446
Garita	52.856	55.369	56.150	58.438	16.425	18.926	20.557	22.067
Poas	55.336	54.323	58.700	63.808	18.690	16.476	14.598	20.193
Tambor	53.486	57.150	62.000	61.858	15.595	16.477	22.543	23.039
Tibas	53.617	58.488	58.748	57.993	14.509	18.510	17.674	17.665
Moravia	55.236	58.620	62.777	63.563	13.836	18.214	21.693	21.493
Curridabat	55.827	49.421	50.200	52.381	19.639	13.387	14.101	15.717
Guadalupe	60.463	66.108	64.878	66.213	21.327	24.830	25.583	24.594
San Francisco	52.932	49.967	57.475	59.087	15.378	12.206	15.535	18.980
San Pedro	52.469	50.387	51.288	54.532	17.197	12.902	11.682	13.909
Vargas Araya	57.133	60.786	61.233	66.117	17.922	22.269	20.066	25.651
Hatillo	52.412	55.441	56.743	53.178	14.614	17.037	18.317	14.868
Sabana	50.327	53.287	56.088	55.173	14.787	17.513	18.312	17.119
San Jose	52.275	47.533	50.780	49.575	16.339	12.199	14.378	14.244
Grecia	53.171	49.987	51.506	54.133	17.892	14.033	16.672	17.622
Guacima	54.520	53.800	57.729	61.690	17.755	15.666	20.732	22.705
Puente Piedra	55.878	51.880	52.221	51.807	18.261	14.816	16.599	15.340
Turrucares	42.004	43.920	44.240	44.743	N/A	N/A	N/A	10.763
Barva	56.477	53.722	60.694	64.467	20.349	16.641	21.455	23.386
Heredia	60.120	57.586	59.723	66.386	21.517	18.732	18.697	27.373
San Pablo	44.707	47.293	49.679	53.100	10.875	12.918	13.165	14.311
Santa Barbara	48.200	49.267	63.267	60.987	12.867	13.320	25.038	23.637
Cartago	62.057	64.350	67.250	68.471	24.651	26.096	20.059	15.545
Guadalupe Car.	55.329	59.571	59.593	60.120	12.448	N/A	N/A	N/A
Pavas	54.200	58.207	62.543	63.457	17.141	20.009	22.557	20.773
Rohmoser	51.621	54.343	56.147	60.213	N/A	11.688	13.845	19.431
Taras	63.231	57.736	63.264	73.207	21.092	N/A	N/A	N/A
Tejar	63.119	64.350	63.800	64.343	24.816	20.505	22.531	N/A
Aguacaliente	58.071	62.729	61.457	58.014	16.966	23.648	21.268	14.989
Guarco	55.338	60.735	61.857	71.114	15.671	N/A	N/A	N/A
S. Raf. Oream.	60.473	58.229	63.136	66.371	17.698	N/A	N/A	N/A
Tobosi	52.636	58.079	60.586	60.350	16.162	16.546	14.137	N/A
Tres Ríos	60.167	53.593	63.279	66.344	21.520	13.899	23.408	26.376
Calle Blancos	57.638	53.647	54.879	54.537	N/A	15.046	15.368	N/A

Table 14. Field Test results for channel 30.

Channel 49

Location	Intensidad (dBuV/m)				MER (dB)			
	2m	4m	6m	8m	2m	4m	6m	8m
Bebedero	66.707	69.531	71.479	74.773	N/A	N/A	N/A	N/A
Ciudad Colon	36.169	36.436	36.221	36.850	N/A	N/A	N/A	N/A
Escazu	55.293	59.407	55.979	58.221	16.220	16.489	N/A	N/A
Santa Ana	46.250	43.564	41.720	45.515	N/A	N/A	N/A	N/A
Uruca	49.307	53.213	52.387	52.331	N/A	17.054	N/A	N/A
Belen	45.473	47.700	52.036	55.541	N/A	N/A	16.565	18.372
Lagunilla	53.941	61.864	63.931	65.307	17.266	20.048	21.520	20.181
Malinche	55.100	64.293	67.727	65.250	15.751	17.063	N/A	N/A
Mercedes Norte	51.736	46.582	51.865	53.900	17.021	N/A	N/A	N/A
Santo Domingo	47.343	49.325	55.486	61.962	N/A	N/A	N/A	17.558
Alajuela	45.700	49.308	53.775	62.127	N/A	N/A	17.141	19.666
Coyol	39.931	45.708	48.836	52.786	N/A	N/A	N/A	17.508
Garita	44.577	41.978	41.213	40.453	N/A	N/A	N/A	N/A
Poas	45.233	45.085	35.400	55.108	N/A	N/A	N/A	16.102
Tambor	49.343	53.564	53.979	51.850	N/A	16.868	N/A	N/A
Tibas	59.114	60.272	64.690	64.582	19.894	17.832	19.004	17.773
Moravia	63.050	62.392	60.089	59.671	21.223	20.105	N/A	17.969
Curridabat	49.064	51.800	49.564	51.988	N/A	16.595	N/A	N/A
Guadalupe	64.825	60.600	65.700	67.367	23.229	17.097	20.277	20.895
San Francisco	54.118	59.793	61.557	59.380	17.152	20.875	20.143	15.749
San Pedro	54.407	51.147	57.357	56.550	18.050	N/A	19.549	N/A
Vargas Araya	49.852	54.981	51.805	57.467	16.320	16.674	N/A	N/A
Hatillo	56.294	59.553	52.060	54.517	17.220	16.881	N/A	16.773
Sabana	50.950	54.294	61.518	57.765	16.900	18.462	23.112	18.544
San Jose	51.858	51.744	55.493	52.587	18.122	17.002	19.738	17.339
Grecia	50.514	45.833	53.017	53.359	16.809	N/A	18.099	17.440
Guacima	43.185	46.927	52.420	49.767	N/A	N/A	17.590	N/A
Puente Piedra	47.495	44.595	44.394	44.247	N/A	N/A	N/A	N/A
Turrucares	41.318	39.950	40.514	39.129	N/A	N/A	N/A	N/A
Barva	42.088	50.271	44.828	49.607	N/A	16.947	N/A	N/A
Heredia	55.829	56.640	54.400	60.250	18.486	18.752	16.178	18.583
San Pablo	42.162	45.153	47.043	51.631	N/A	N/A	N/A	16.209
Santa Barbara	45.518	49.876	52.331	50.786	N/A	17.636	16.006	N/A
Cartago	55.979	63.357	64.413	70.586	17.400	17.913	N/A	N/A
Guadalupe Cartago	55.400	51.623	57.779	59.407	18.739	17.284	16.000	N/A
Pavas	49.336	57.000	52.681	61.414	N/A	16.679	N/A	N/A
Rohmoser	48.831	50.223	53.069	54.633	N/A	N/A	N/A	N/A
Taras	57.679	60.000	68.238	75.000	17.938	N/A	N/A	N/A
Tejar	61.647	61.093	61.879	63.562	19.397	N/A	17.270	N/A
Aguacaliente	57.129	60.336	57.986	62.271	18.451	18.433	N/A	16.713
Guarco	56.557	63.521	64.514	75.743	N/A	N/A	N/A	N/A
San Rafael de Oreamuno	66.029	63.707	70.621	67.073	17.875	N/A	N/A	N/A
Tobosi	55.743	58.114	61.293	60.557	16.722	17.785	N/A	N/A
Tres Ríos	48.347	47.321	49.400	50.543	N/A	N/A	N/A	N/A
Calle Blancos	56.693	55.515	57.714	57.577	19.666	17.815	18.986	16.778

Table 15. Field Test results for channel 49.

From all the measurement results for the 45 chosen locations, there are some sites that have an interesting behavior between the signal level and the MER at different heights, because of that, it is considered necessary to perform new measurements in some of those sites to verify if there are interesting behaviors in the quality of the signal and the final user experience.

Site Malinche

For this location it was interesting the behavior of the signal strength, that has very similar values for all the heights, and all of them have a level that should be enough to have a good reception of the signal but the MER measurement shows the opposite behavior and as the height decreases the MER value increases, making the receiving scenario at 2m the best scenario for this location. This situation that was confirmed with a second measurement performed other day obtaining the same behavior. These results justify the criteria that the MER and the signal strength are not related variables, so it is necessary to measure both in order to evaluate a DTV transmission.

Channel 18	**06/02/2019**				**15/02/2019**			
Height	2m	4m	6m	8m	2m	4m	6m	8m
Level (dBuV/m)	81.11	75.81	83.01	79.90	73.08	78.81	77.91	78.19
MER (dB)	32.52	29.51	18.34	18.79	24.70	26.01	16.65	18.26
Channel 30	**06/02/2019**				**15/02/2019**			
Height	2m	4m	6m	8m	2m	4m	6m	8m
Level (dBuV/m)	63.45	68.17	75.04	75.59	64.50	68.14	73.98	73.80
MER (dB)	22.90	23.75	18.37	21.76	16.34	23.56	18.46	19.24
Channel 49	**06/02/2019**				**15/02/2019**			
Height	2m	4m	6m	8m	2m	4m	6m	8m
Level (dBuV/m)	55.10	64.29	67.73	65.25	59.66	63.12	65.63	66.57
MER (dB)	15.75	17.06	N/A	N/A	19.19	N/A	N/A	N/A

Table 16. Comparison for measurements made at site Malinche on the 6th and 15th of February of 2019.

In the following figures can be observed the effects of the measured values described in Table 16, in the case of channel 18 can be observed how the fuzziness of the constellation increases while the measuring height increases and how only at three heights was possible to perform the reception of the signal, the equipment failed to receive the signal at 6m, which is the height that presented the lowest MER value.

For the case of channel 30 can be observed how the fuzziness of the constellation increases while the measuring height increases but the MER values are still sufficient so the equipment can perform the signal reception at all heights.

And finally, in the case of channel 49 can be observed how only at the height of 2 m is obtained a fuzzy constellation but with sufficient MER value in order to perform reception, at the other heights the difference between the signal level and the noise observed is so low that the equipment failed to perform the reception and demodulate the signal.

Channel 18

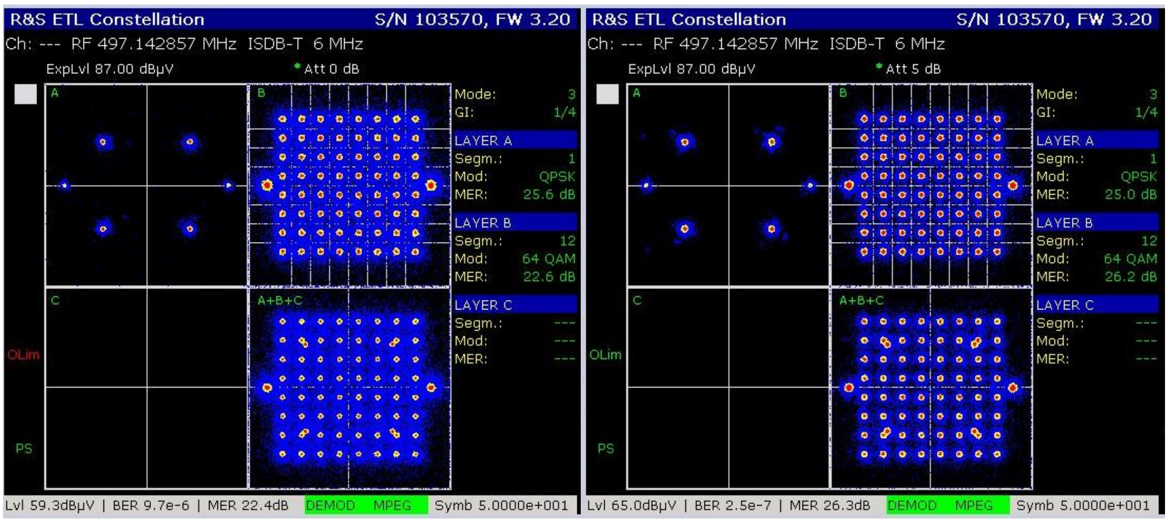

Figure 34. Received constellation for channel 18 at measuring heights of 2m and 4 m.

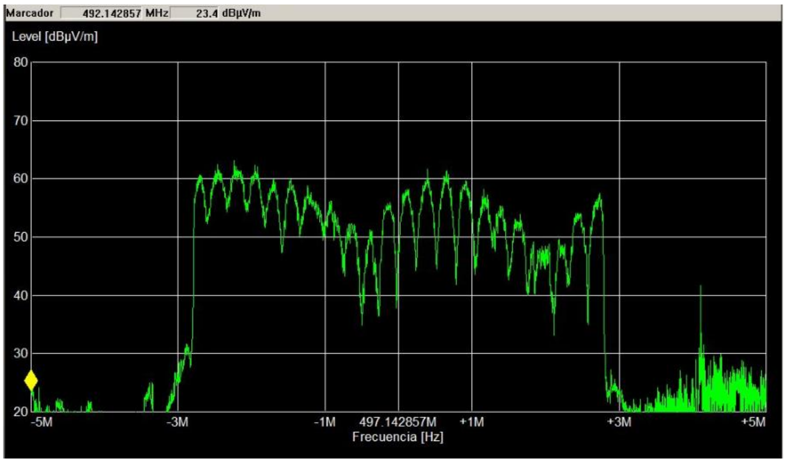

Figure 35. Measurement of channel 18 at 2m.

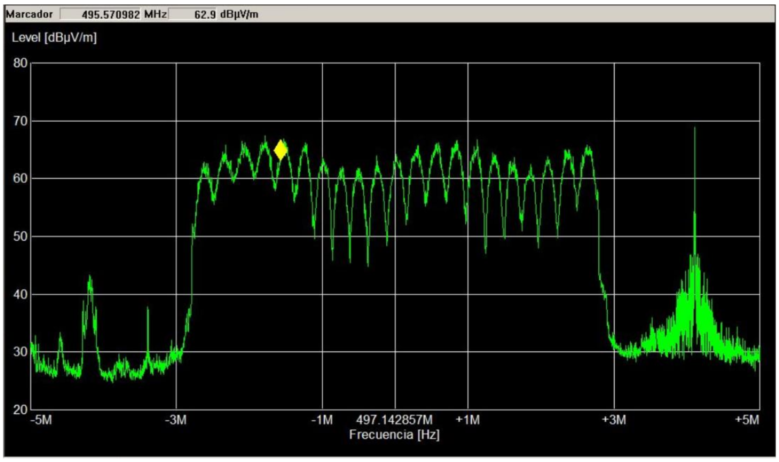

Figure 36. Measurement of channel 18 at 4m.

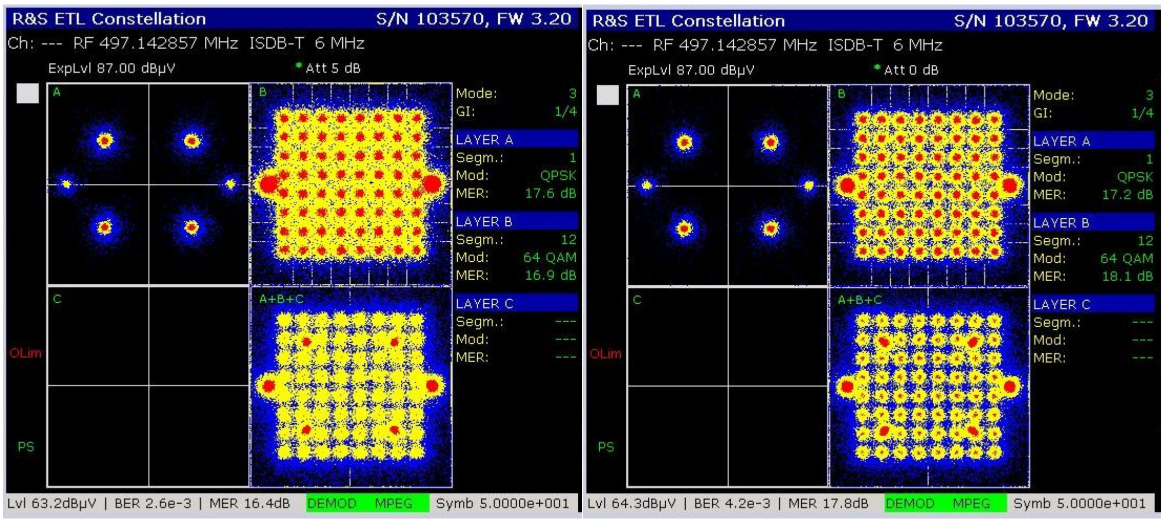

Figure 37. Received constellation for channel 18 at measuring heights of 6m and 8 m.

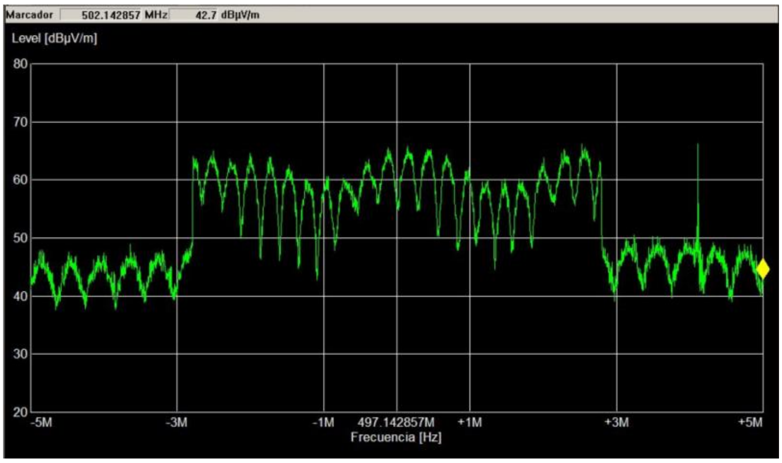

Figure 38. Measurement of channel 18 at 6m.

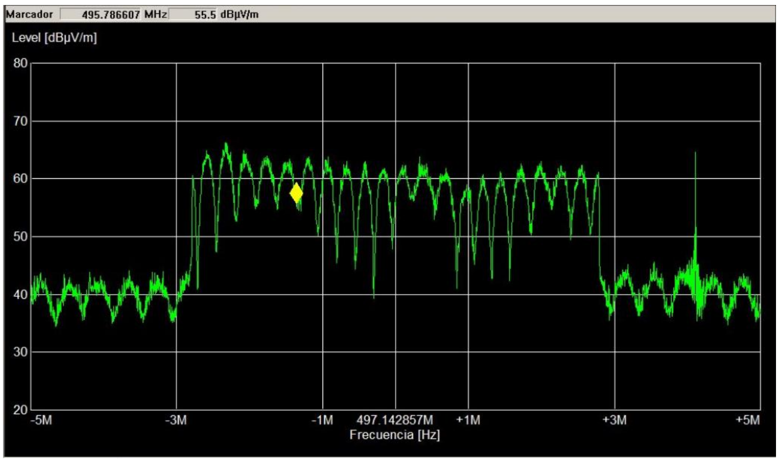

Figure 39. Measurement of channel 18 at 8m.

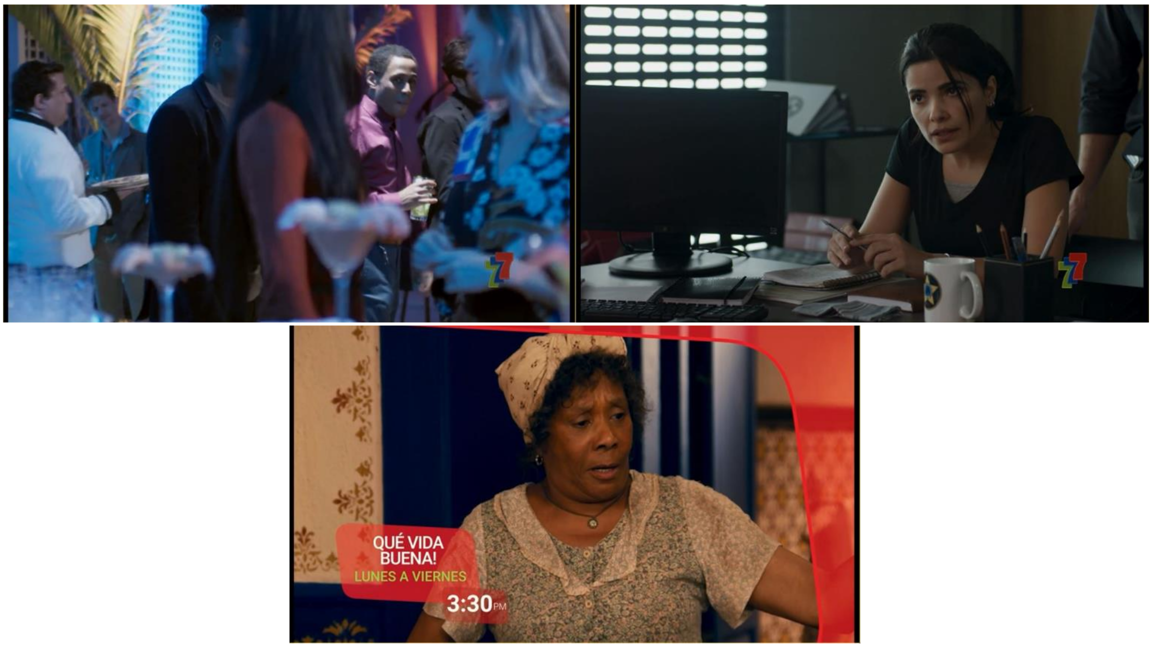

Figure 40. Received image of channel 18 at 2m, 4m and 8m.

Channel 30

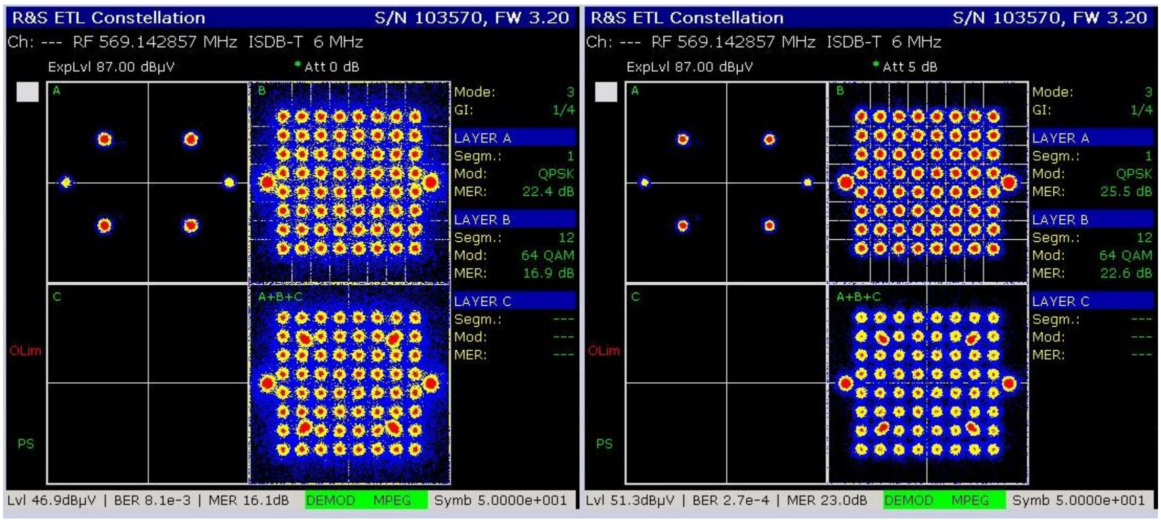

Figure 41. Received constellation for channel 30 at measuring heights of 2m and 4 m.

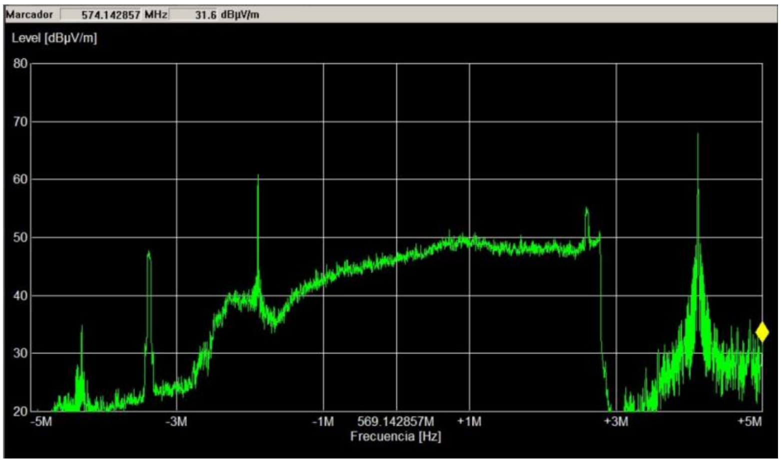

Figure 42. Measurement of channel 30 at 2m.

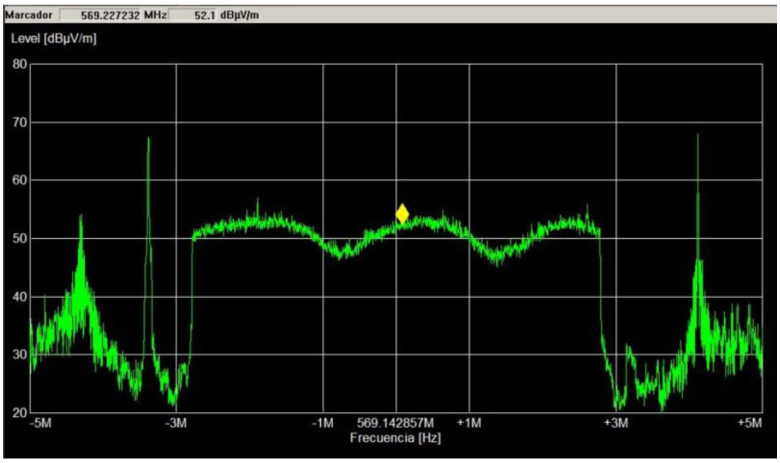

Figure 43. Measurement of channel 30 at 4m.

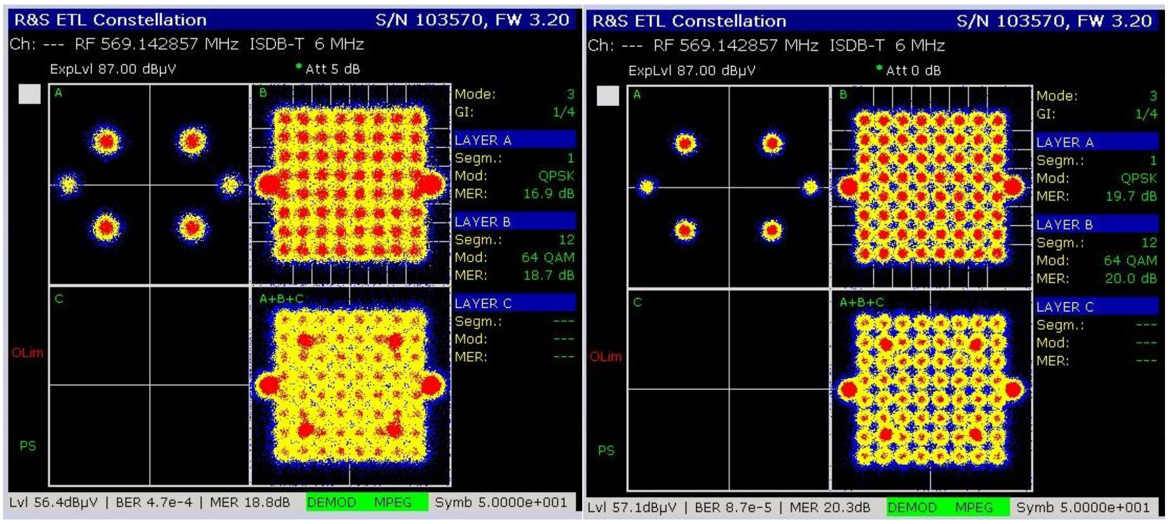

Figure 44. Received constellation for channel 30 at measuring heights of 6 m and 8 m.

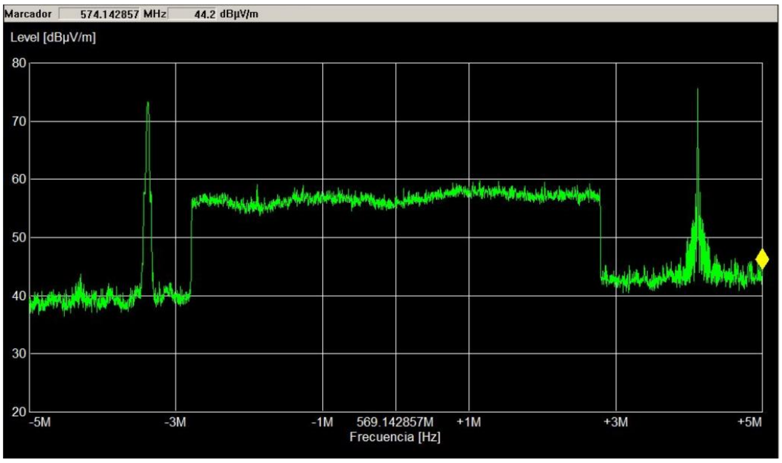

Figure 45. Measurement of channel 30 at 6m.

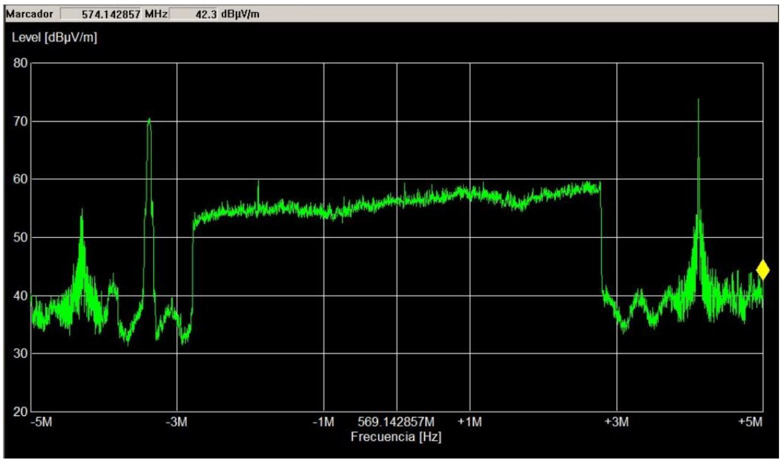

Figure 46. Measurement of channel 30 at 8m.

Figure 47. Received image of channel 30 at 2m, 4m, 6m and 8m.

Channel 49

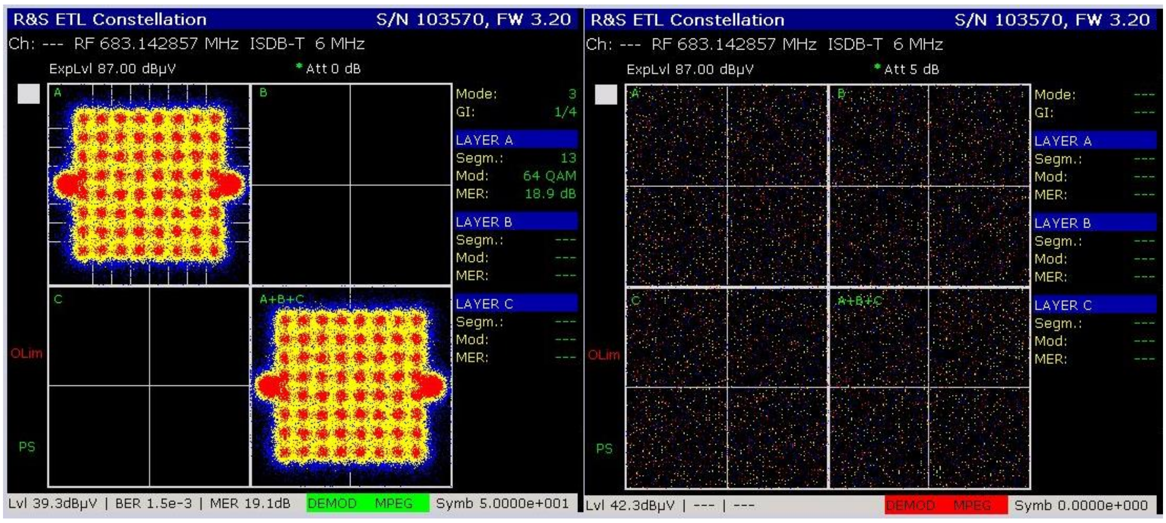

Figure 48. Received constellation for channel 49 at measuring heights of 2m and 4 m (6 m and 8 m).

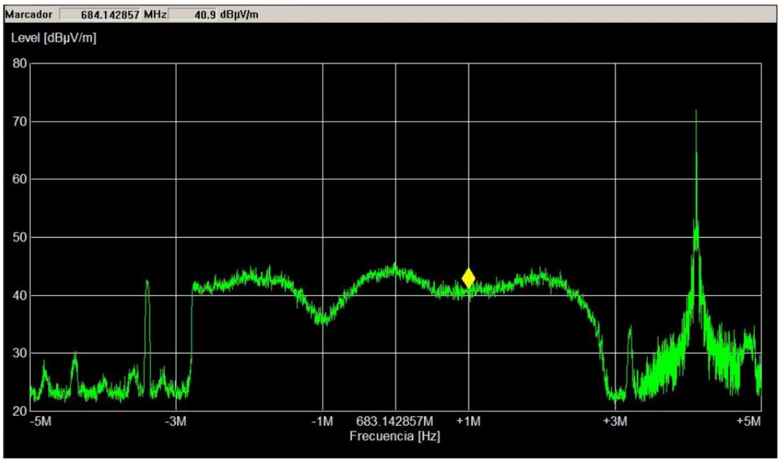

Figure 49. Measurement of channel 49 at 2m.

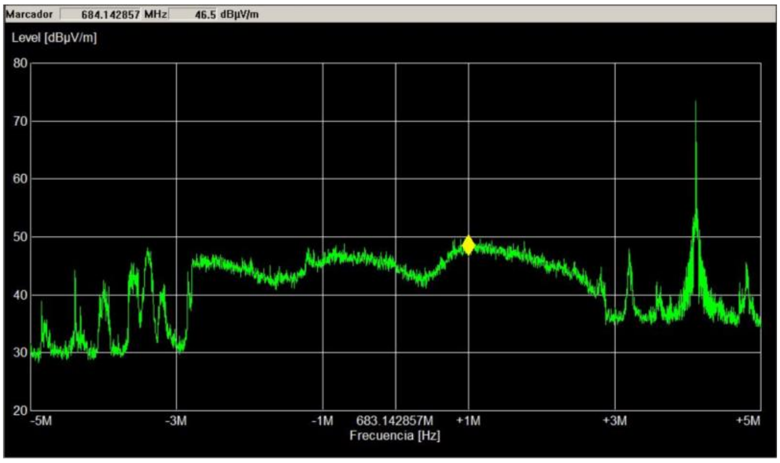

Figure 50. Measurement of channel 49 at 4m.

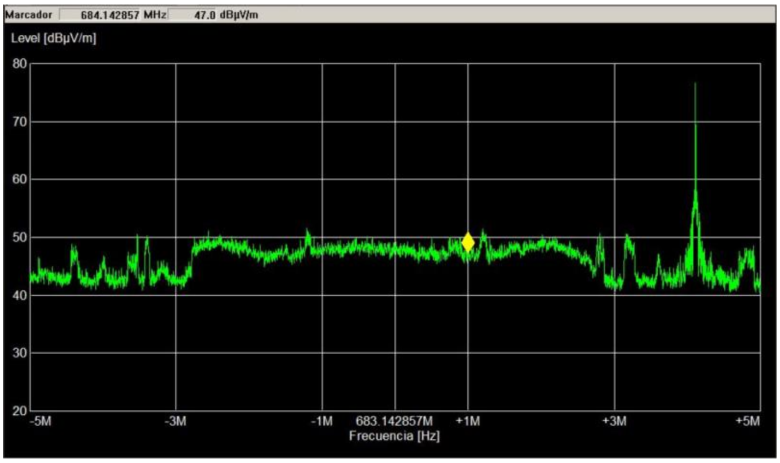

Figure 51. Measurement of channel 49 at 6m.

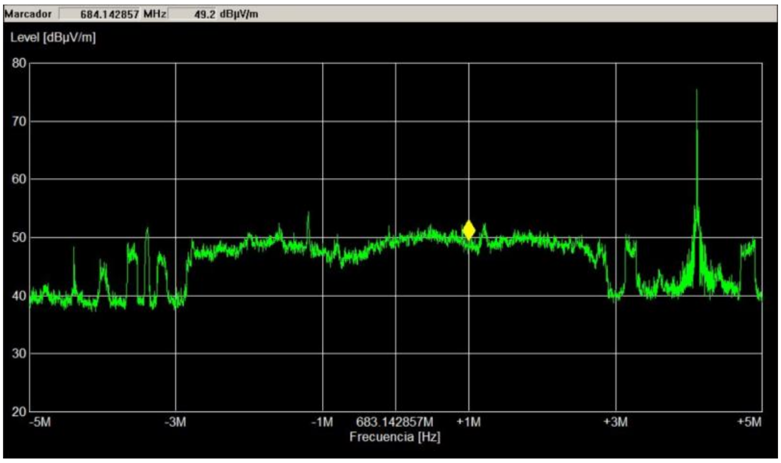

Figure 52. Measurement of channel 49 at 8m.

Figure 53. Received image of channel 49 at 2m.

Site Tejar

For this location it was interesting the behavior of the MER, because the higher values were obtained at a measuring height of 2m and 6m, being the maximum at 2m. But for the signal strength the behavior consists that the received level decreases according the measuring height decreases, thus, despite that the worst received signal level is achieved at a measuring height of 2 m, at this height is received the best MER, making the receiving scenario at 2m the best scenario for this location. This situation was confirmed with a second measurement performed other day obtaining the same behavior. These results justify the criteria that the MER and the signal strength are not related variables, so it is necessary to measure both in order to evaluate a DTV transmission.

Channel 18	**24/01/2019**				**15/02/2019**			
Height	2m	4m	6m	8m	2m	4m	6m	8m
Level (dBuV/m)	69.25	72.63	70.66	72.43	69.45	73.97	70.68	81.03
MER (dB)	25.66	18.79	22.25	N/A	21.79	17.56	18.10	15.65
Channel 30	**24/01/2019**				**15/02/2019**			
Height	2m	4m	6m	8m	2m	4m	6m	8m
Level (dBuV/m)	63.12	64.35	63.8	64.34	59.63	58.74	59.62	67.80
MER (dB)	24.82	20.51	22.53	N/A	17.53	13.99	14.16	N/A
Channel 49	**24/01/2019**				**15/02/2019**			
Height	2m	4m	6m	8m	2m	4m	6m	8m
Level (dBuV/m)	61.65	61.09	61.88	63.56	56.41	57.66	58.93	63.43
MER (dB)	19.40	N/A	17.27	N/A	16.97	N/A	N/A	N/A

Table 17. Comparison for measurements made at site Tejar on the 6th and 15th of February of 2019.

In the following figures can be observed the effects of the measured values described in Table 17, in the case of channel 18 can be observed how the fuzziness of the constellation increases while the measuring height increases, despite the increase in the signal level. Also, it can be observed that only at the heights of 2m and 6m the equipment was able to receive the signal because of the low MER values experienced at height of 4 m and 8 m.

For the case of channel 30 can be observed that the fuzziness of the constellation increases while the measuring height increases, despite the increase in the signal level, causing a drop in the MER value, situation that caused that the equipment failed to receive the signal at heights different than 2 m.

And finally, in the case of channel 49 can be observed how only at the height of 2 m is obtained a fuzzy constellation but without the sufficient MER value in order to perform reception, at the other heights the difference between the signal level and the noise observed is so low that the equipment failed to perform the reception and demodulate the signal.

Channel 18

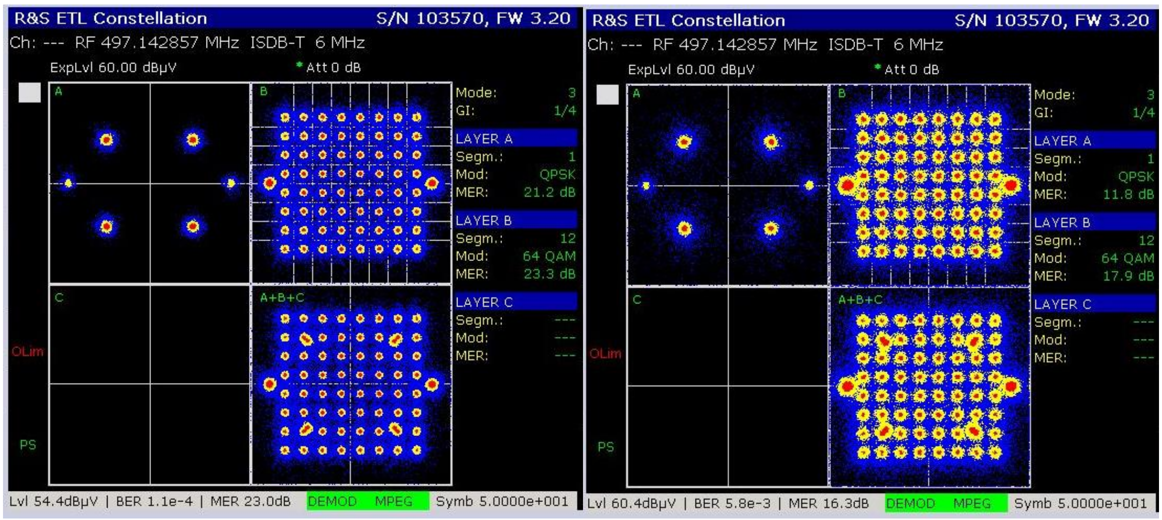

Figure 54. Received constellation for channel 18 at measuring heights of 2 m and 4 m.

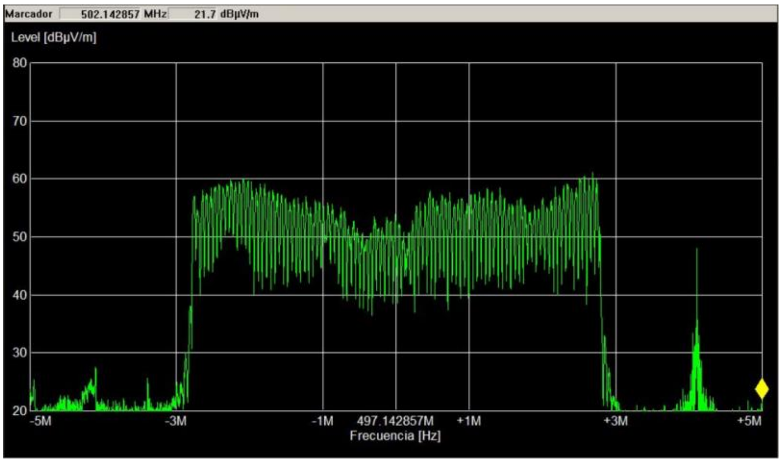

Figure 55. Measurement of channel 18 at 2m.

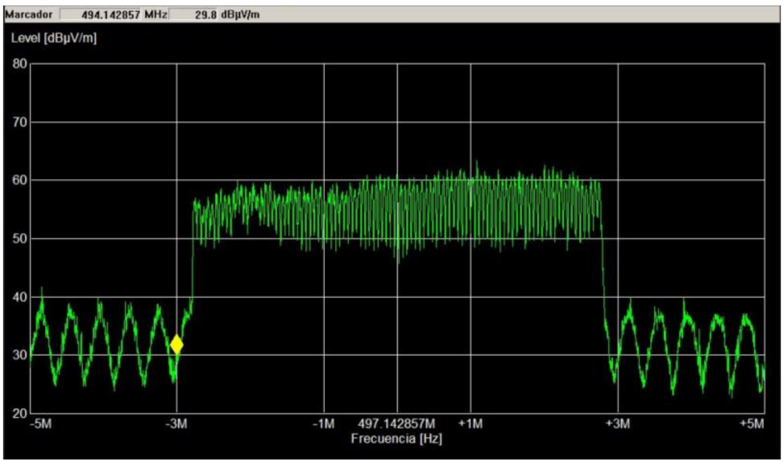

Figure 56. Measurement of channel 18 at 4m.

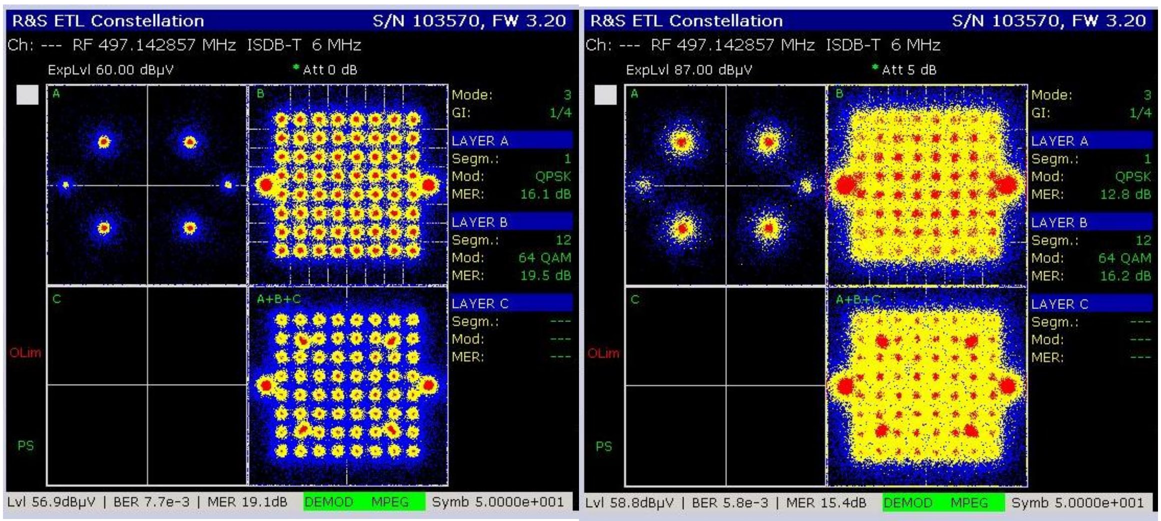

Figure 57. Received constellation for channel 18 at measuring heights of 6 m and 8 m.

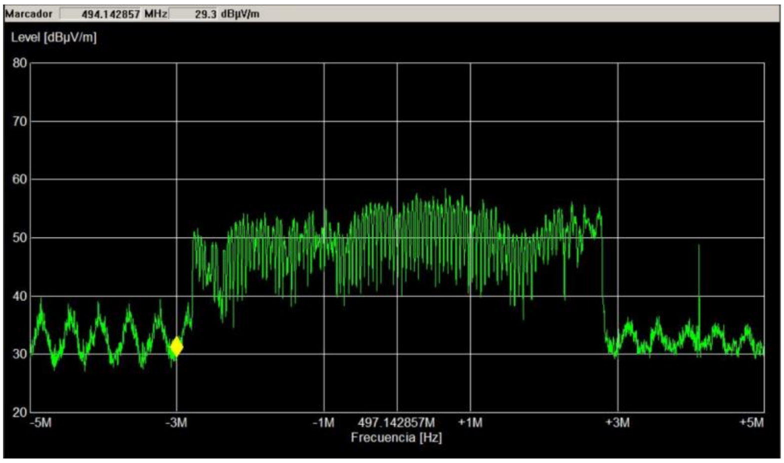

Figure 58. Measurement of channel 18 at 6m.

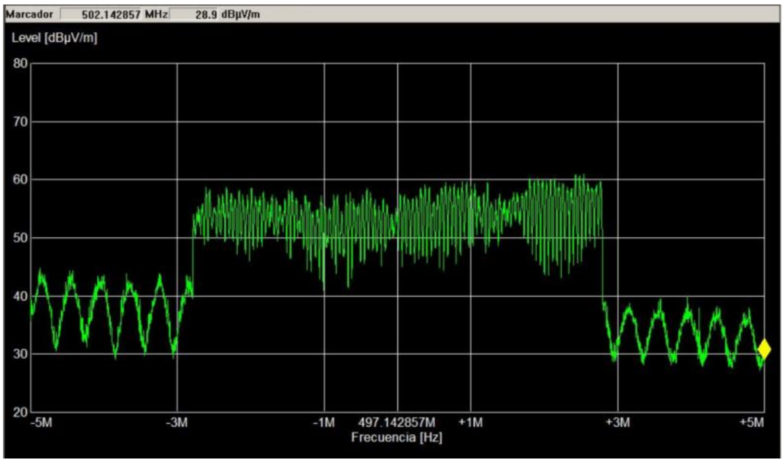

Figure 59. Measurement of channel 18 at 8m.

Figure 60. Received image of channel 18 at 2m and 6m.

Channel 30

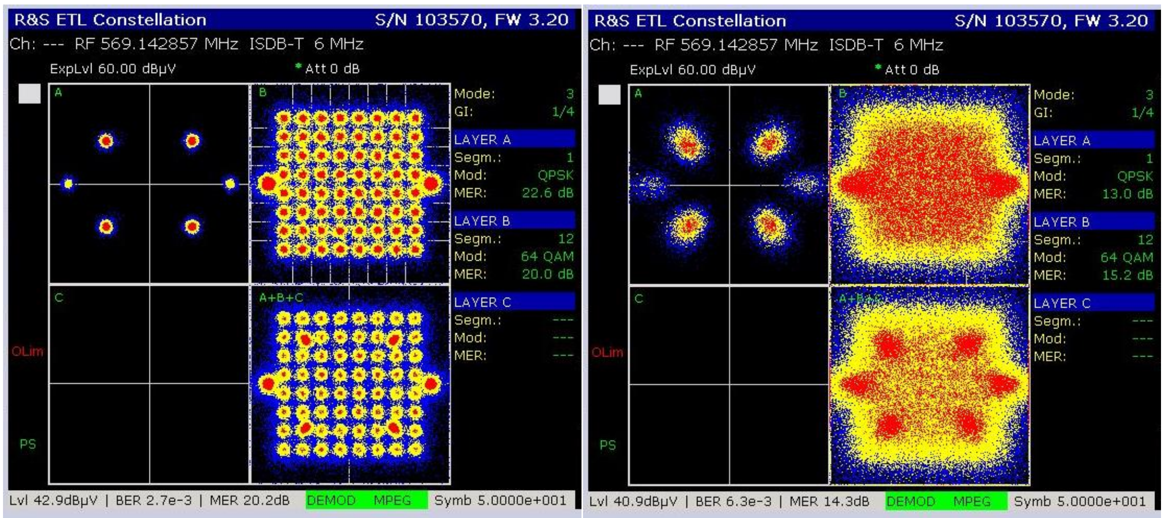

Figure 61. Received constellation for channel 30 at measuring heights of 2 m and 4 m.

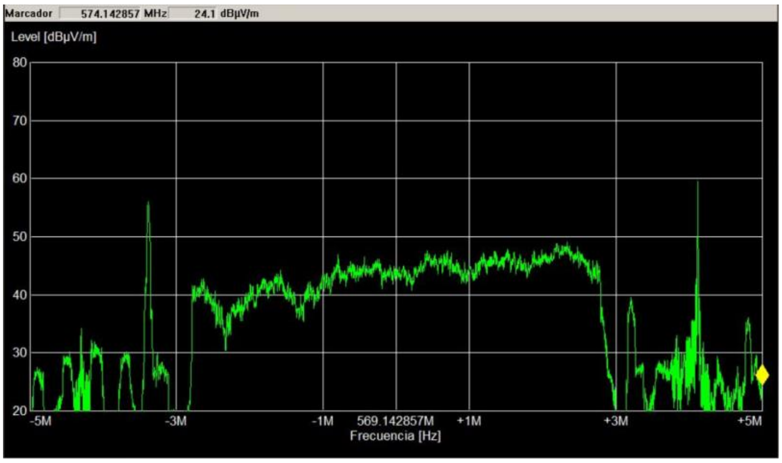

Figure 62. Measurement of channel 30 at 2m.

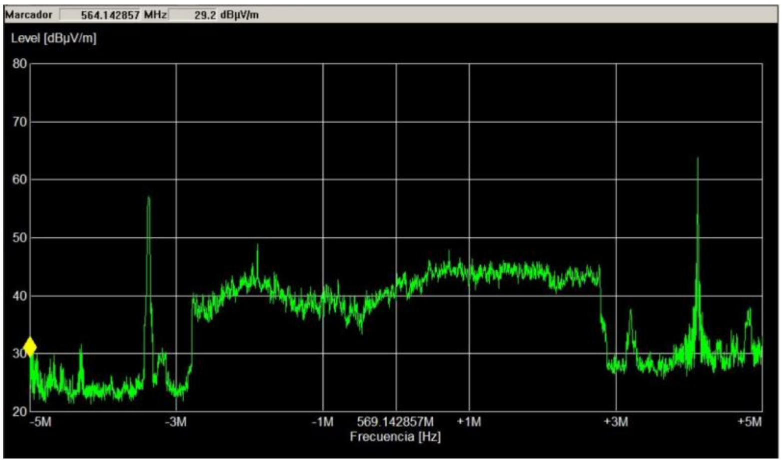

Figure 63. Measurement of channel 30 at 4m.

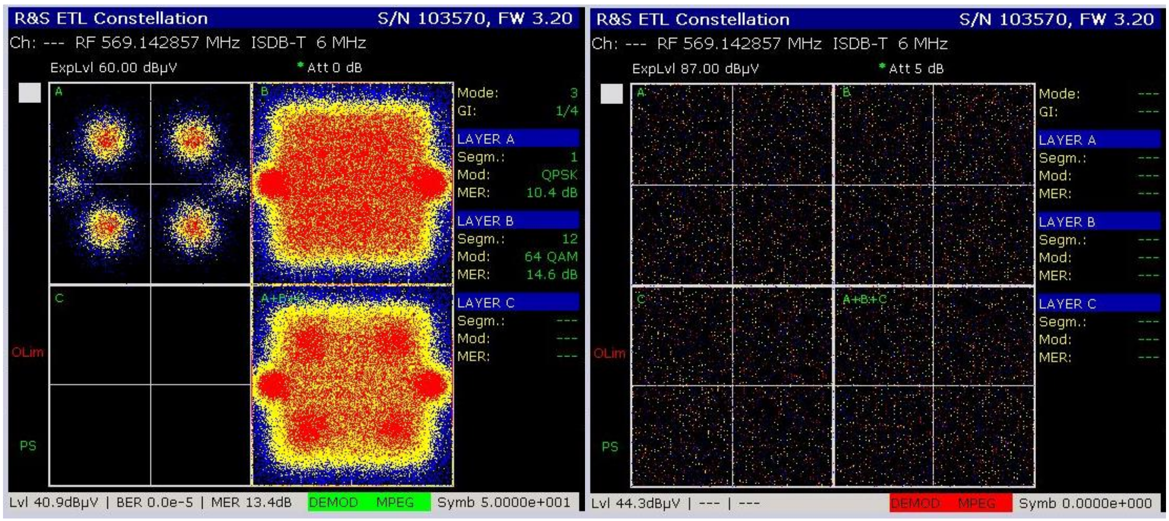

Figure 64. Received constellation for channel 30 at measuring heights of 6 m and 8 m.

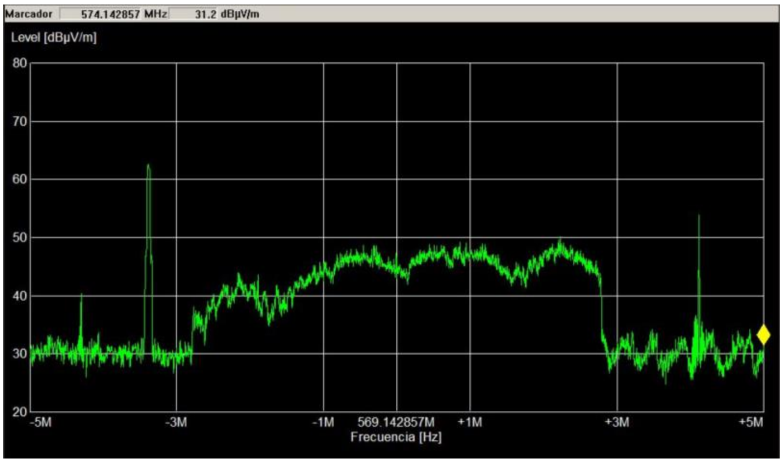

Figure 65. Measurement of channel 30 at 6m.

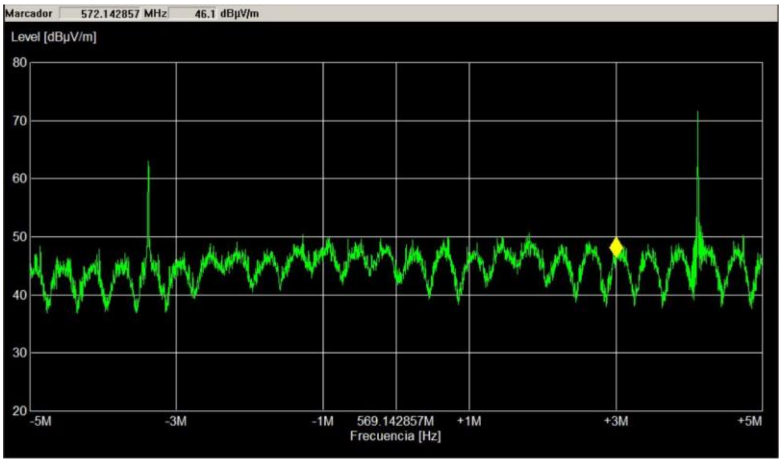

Figure 66. Measurement of channel 30 at 8m.

Figure 67. Received image of channel 30 at 2m.

Channel 49

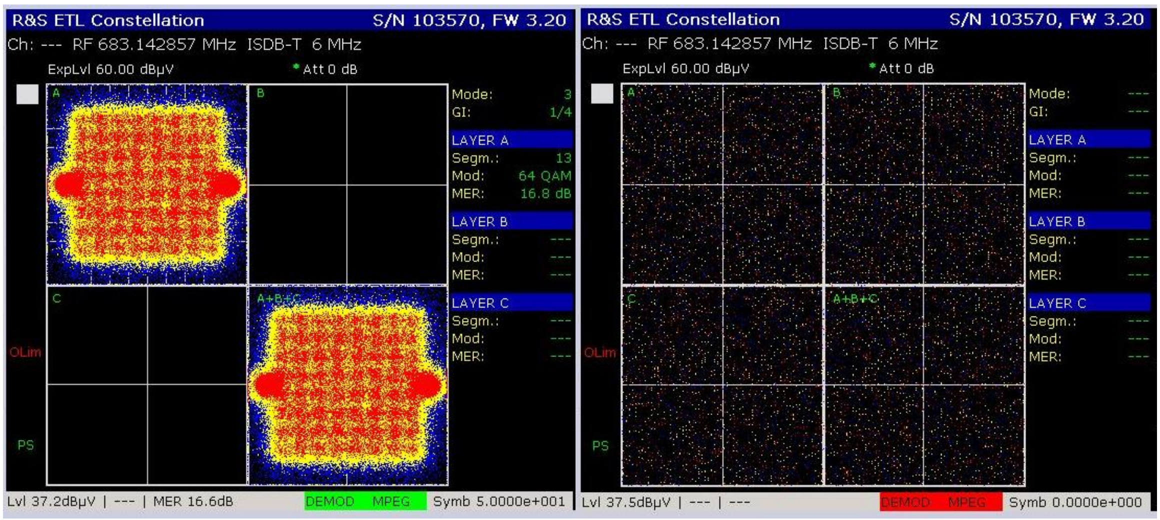

Figure 68. Received constellation for channel 49 at measuring heights of 2 m and 4 m (6 m and 8 m).

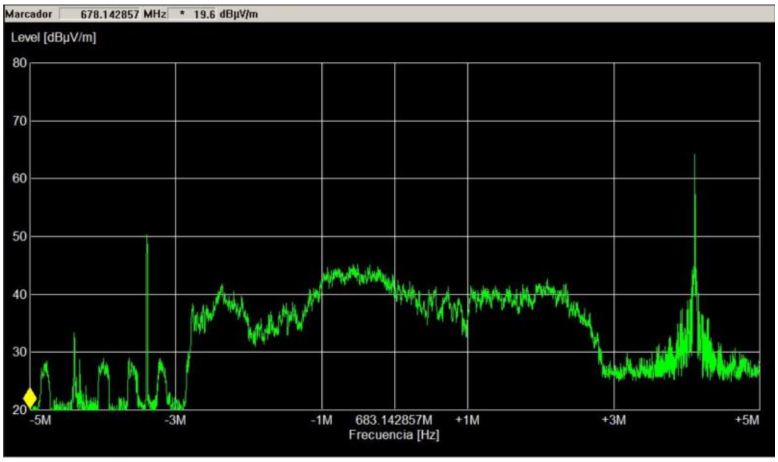

Figure 69. Measurement of channel 49 at 2m.

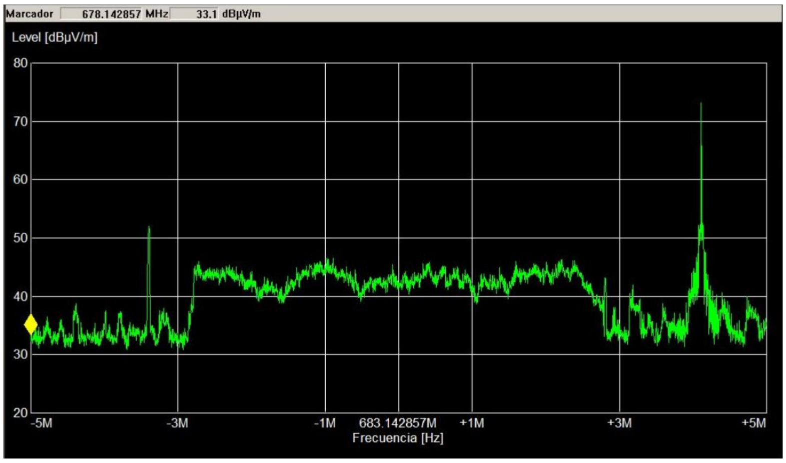

Figure 70. Measurement of channel 49 at 4m.

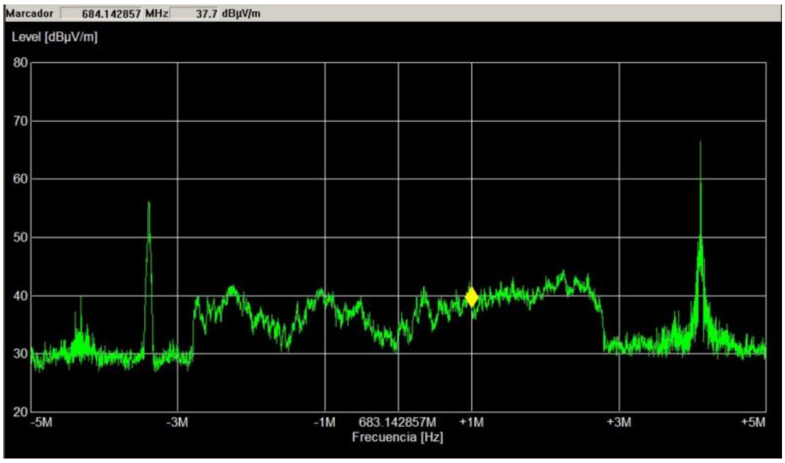

Figure 71. Measurement of channel 49 at 6m.

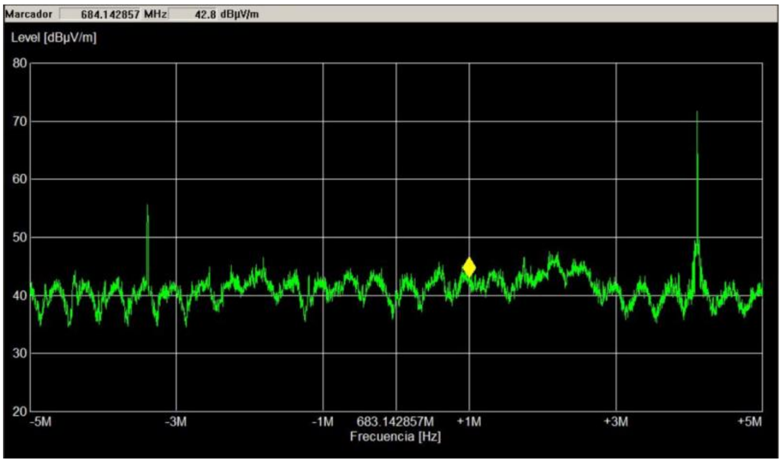

Figure 72. Measurement of channel 49 at 8m.

Comparison between simulations and measurements

Another aspect that can be analyzed from the measurement results is the difference from the values obtained during the measurement procedure and the expected values obtained from the simulations performed. This process is even recommended in the Rep. ITU-R BT 2035-2 as valuable step that allows to evaluate the performance of the propagation model and even provide important information to help improve the propagation model used.

In this case, it will be compared the root-mean-square error (RMSE) of the three measured channels at the different heights to observe which channel and which height has the lowest variation from the expected value.

Channel	Height	2 m	4 m	6 m	8 m
18	N	41	41	43	43
	Square Sum	3376.21997	3894.16692	4958.58446	5454.7143
	RMSE	**9.07451533**	**9.74575195**	**10.7385249**	**11.2629402**
30	N	45	45	45	45
	Square Sum	8096.35626	11064.4869	11170.4983	12269.0749
	RMSE	**13.4133899**	**15.680481**	**15.7554211**	**16.5119989**
49	N	45	45	45	45
	Square Sum	10912.1133	13416.6646	16563.6042	17718.7824
	RMSE	**15.5721356**	**17.2669656**	**19.1854135**	**19.843153**

Table 18. RMSE values for all the channels at different heights.

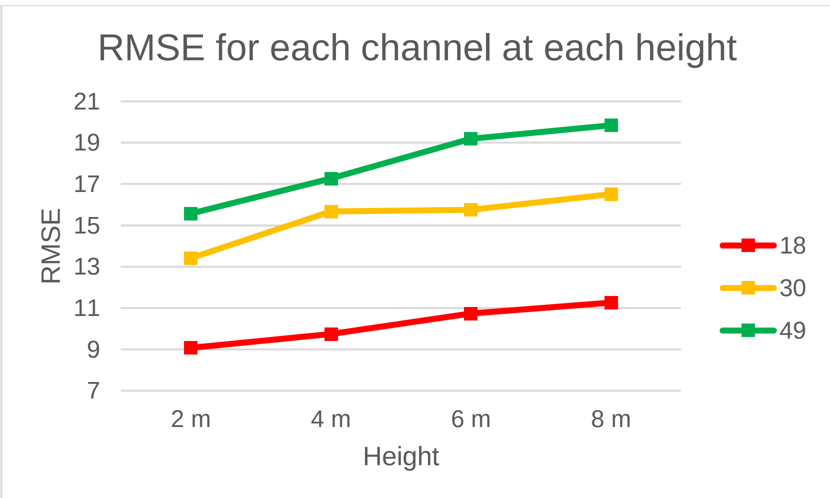

Figure 73. RMSE for each channel at each height.

From the RMSE results is observed that channel 18 is the one with the lowest values at each height and with the smaller differences between heights, situation that can be a result of the operation as SFN and also the improvement of the prediction by considering more than one transmitter.

For the case of channel 30, it has higher RMSE values than channel 18 and the difference between heights increases but with a low slope; in the other case, channel 49 is the one with highest RMSE values and the difference between heights has a steeper slope, which means that as long as the measuring height increases, the difference with the expected values is also larger.

From the different results obtained, it has been observed that the behavior of channel 49 was atypical, besides the transmitters been located really close between them and having similar transmission parameters the reception results for this channel were highly unsatisfactory. As seen from the measurement results, they were several locations were the equipment was uncapable of demodulating the signal and detect parameters beside the signal level and in the case of the RSME is observed that this channel is the one that differs the most from the expected values. From this behavior is concluded that the transmitter was operating with different parameters from the ones used for the simulations or there is a failure in the equipment, even though the broadcaster assured that the parameters were correct, and the transmitter was working properly.

Appendix 3. Statistical Analysis

In this appendix it is shown the statistical analysis performed over the data obtained during the measurements.

It is important to mention that prior to any analysis it was performed an adjustment to the variable MER to ignore the missing values in the test that variable is considered, which correspond to 138 values from the total of 540 measurements.

First, it was performed a scatter plot for all the measurements using the variables signal level and MER, and using a color scale for the channels, as shown in Figure 74, where it can be observed that channel 18 (blue dots) apparently have a behavior that is different from the other channels, to prove that is necessary to perform an analysis of variance to demonstrate if channel 18 has a significant difference against the others.

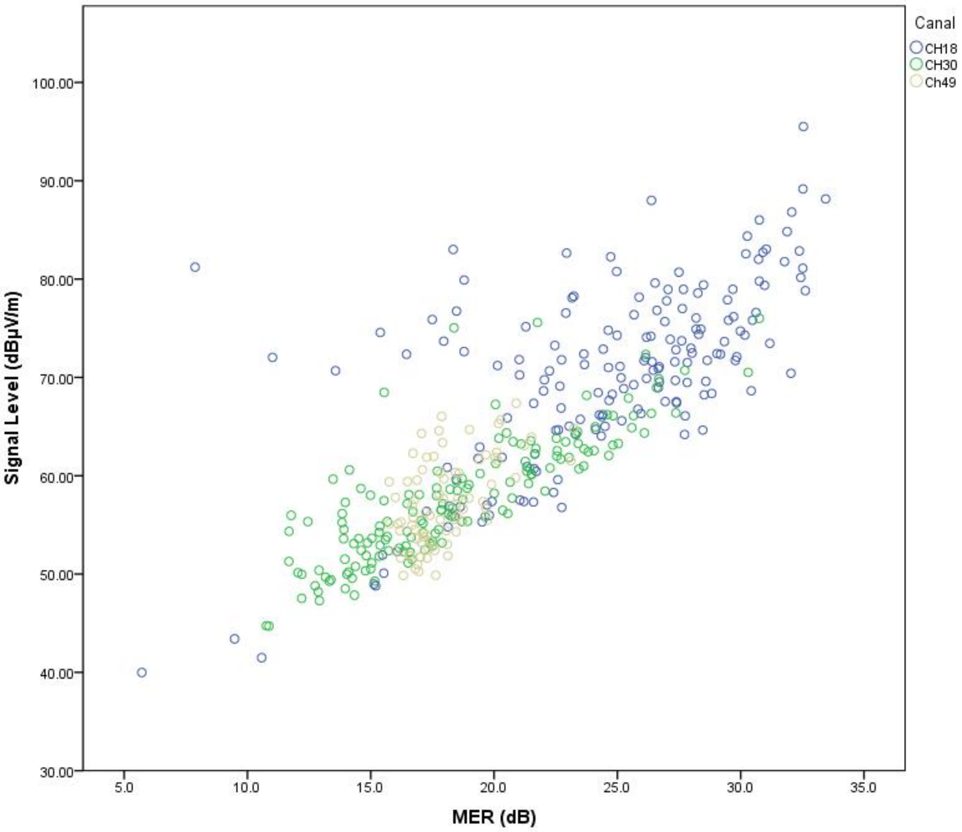

Figure 74. Scatter plot of signal level vs. MER.

ANOVA

Height			Sum of Squares	df	Mean Square	F	Sig.
2	Level	Between Groups	7837.61	2	3918.8	63.67	0
		Within Groups	8124.29	132	61.548		
		Total	15961.9	134			
	MER	Between Groups	1520.11	2	760.053	43.11	0
		Within Groups	1851.08	105	17.629		
		Total	3371.19	107			
4	Level	Between Groups	6105.19	2	3052.59	47.97	0
		Within Groups	8399.4	132	63.632		
		Total	14504.6	134			
	MER	Between Groups	959.941	2	479.971	25.94	0
		Within Groups	1887.66	102	18.506		
		Total	2847.6	104			
6	Level	Between Groups	6353.56	2	3176.78	45.19	0
		Within Groups	9280.02	132	70.303		
		Total	15633.6	134			
	MER	Between Groups	767.437	2	383.719	18.45	0
		Within Groups	1934.11	93	20.797		
		Total	2701.54	95			
8	Level	Between Groups	5951.73	2	2975.87	41.63	0
		Within Groups	9435.78	132	71.483		
		Total	15387.5	134			
	MER	Between Groups	716.159	2	358.079	17.64	0
		Within Groups	1826.65	90	20.296		
		Total	2542.81	92			

Table 19. Analysis of variance for the variable channel.

From the analysis of variance is obtained that the significance of the channels for each height is under the threshold of 5%, so it can be established that the mean of all the channels are not equal, but is necessary to verify if all the channels are different among them or if there is a relation between some of them. In order to obtain that, it is performed a multiple comparison test with the Tukey HSD (Honest Significant Difference) [23].

Tukey HSD consist on a test based on the studentized range distribution, that is executed after an analysis of variance that throws as a conclusion that the results present a significance below the 5% threshold, which implies that at least one group of data has a mean that differs from the other groups. The objective of the Tukey HSD test is to determine which groups of data differ among them, by means of a pairwise comparison using the Honest Significant Difference

In Table 20 can be observed the results of the comparisons performed by the Tukey HSD test, that compares each channel with the other channels for both cases, signal level and MER, at each of the measuring heights. In this case, when the significance surpasses the 5% threshold implies that the compared values have similar means values. As it can be observed, when channel 18 is being compared with the other channels, at each measuring height the significance of the signal level or the MER is below the 5%, indicating that the channels 18 differs from channel 30 and 49 in both signal level and MER.

Multiple Comparisons

Tukey HSD

Height	Dependent Variable	(I) CH	(J) CH	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
2	Level	18	30	14.43539*	1.65392	0	10.5149	18.3559
			49	17.46310*	1.65392	0	13.5426	21.3836
		30	18	-14.43539*	1.65392	0	-18.356	-10.515
			49	3.02771	1.65392	0.16	-0.8928	6.9482
		49	18	-17.46310*	1.65392	0	-21.384	-13.543
			30	-3.02771	1.65392	0.16	-6.9482	0.8928
	MER	18	30	7.853102672016352*	0.91241	0	5.68393	10.0223
			49	7.134919101730077*	1.07622	0	4.5763	9.69354
		30	18	-7.853102672016352*	0.91241	0	-10.022	-5.6839
			49	-0.71818357	1.09874	0.79	-3.3303	1.89396
		49	18	-7.134919101730077*	1.07622	0	-9.6935	-4.5763
			30	0.71818357	1.09874	0.79	-1.894	3.33033
4	Level	18	30	12.69008*	1.68169	0	8.7037	16.6764
			49	15.44051*	1.68169	0	11.4542	19.4269
		30	18	-12.69008*	1.68169	0	-16.676	-8.7037
			49	2.75044	1.68169	0.23	-1.2359	6.7368
		49	18	-15.44051*	1.68169	0	-19.427	-11.454
			30	-2.75044	1.68169	0.23	-6.7368	1.2359
	MER	18	30	6.134768474104842*	0.95269	0	3.86889	8.40065
			49	6.117039431363676*	1.1069	0	3.48438	8.7497
		30	18	-6.134768474104842*	0.95269	0	-8.4006	-3.8689
			49	-0.017729043	1.1365	1	-2.7208	2.68534
		49	18	-6.117039431363676*	1.1069	0	-8.7497	-3.4844
			30	0.017729043	1.1365	1	-2.6853	2.7208
6	Level	18	30	12.14083*	1.76765	0	7.9507	16.3309
			49	16.13200*	1.76765	0	11.9419	20.3221
		30	18	-12.14083*	1.76765	0	-16.331	-7.9507
			49	3.99117	1.76765	0.07	-0.1989	8.1813
		49	18	-16.13200*	1.76765	0	-20.322	-11.942
			30	-3.99117	1.76765	0.07	-8.1813	0.1989
	MER	18	30	5.559949441484601*	1.021	0	3.12811	7.99179
			49	6.003141285639504*	1.33976	0	2.81208	9.19421
		30	18	-5.559949441484601*	1.021	0	-7.9918	-3.1281
			49	0.443191844	1.35908	0.94	-2.7939	3.68026
		49	18	-6.003141285639504*	1.33976	0	-9.1942	-2.8121
			30	-0.443191844	1.35908	0.94	-3.6803	2.79387
8	Level	18	30	11.62704*	1.78242	0	7.4019	15.8522
			49	15.66238*	1.78242	0	11.4372	19.8875
		30	18	-11.62704*	1.78242	0	-15.852	-7.4019
			49	4.03535	1.78242	0.07	-0.1898	8.2605
		49	18	-15.66238*	1.78242	0	-19.888	-11.437
			30	-4.03535	1.78242	0.07	-8.2605	0.1898
	MER	18	30	4.667705321167649*	1.04125	0	2.18631	7.1491
			49	6.848996372868172*	1.28373	0	3.78973	9.90826
		30	18	-4.667705321167649*	1.04125	0	-7.1491	-2.1863
			49	2.181291052	1.30052	0.22	-0.918	5.28055
		49	18	-6.848996372868172*	1.28373	0	-9.9083	-3.7897
			30	-2.181291052	1.30052	0.22	-5.2806	0.91797

*. The mean difference is significant at the 0.05 level.

Table 20. Multiple comparisons for the variable channel by Tukey HSD.

Height=2

Tukey HSD[a]

CH	N	Subset for alpha = 0.05	
		1	2
49	45	51.6247	
30	45	54.6524	
18	45		69.0878
Sig.		0.164	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 45.000.

Table 21. Homogeneous subset for signal strength at 2m.

Height=4

Tukey HSD[a]

CH	N	Subset for alpha = 0.05	
		1	2
49	45	53.4487	
30	45	56.1992	
18	45		68.8892
Sig.		0.234	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 45.000.

Table 22. Homogeneous subset for signal strength at 4m.

Height=6

Tukey HSD[a]

CH	N	Subset for alpha = 0.05	
		1	2
49	45	54.8978	
30	45	58.889	
18	45		71.0298
Sig.		0.065	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 45.000.

Table 23. Homogeneous subset for signal strength at 6m.

Height=8

Tukey HSD[a]

CH	N	Subset for alpha = 0.05	
		1	2
49	45	57.133	
30	45	61.1684	
18	45		72.7954
Sig.		0.065	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 45.000.

Table 24. Homogeneous subset for signal strength at 8m.

Height=2

Tukey HSD[a,b]

CH	N	Subset for alpha = 0.05	
		1	2
30	40	17.3623	
49	23	18.0805	
18	45		25.2154
Sig.		0.767	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 33.076.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 25. Homogeneous subset for MER at 2m.

Height=4

Tukey HSD[a,b]

CH	N	Subset for alpha = 0.05	
		1	2
30	38	17.734	
49	23	17.7517	
18	44		23.8688
Sig.		1	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 32.425.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 26. Homogeneous subset for MER at 4m.

Height=6

Tukey HSD[a,b]

CH	N	Subset for alpha = 0.05	
		1	2
49	16	18.5737	
30	38	19.0169	
18	42		24.5768
Sig.		0.933	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 26.637.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 27. Homogeneous subset for MER at 6m.

Height=8

Tukey HSD[a,b]

CH	N	Subset for alpha = 0.05	
		1	2
49	18	17.7861	
30	36	19.9674	
18	39		24.6351
Sig.		0.177	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 27.529.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 28. Homogeneous subset for MER at 8m.

Considering the result obtained in the previous test, that throws the conclusion that channel 18 differs from the other channels, channel 30 and 40 can be considered as only one group. Then, from an analysis of variance of the variable height is obtained the significance for the signal level and MER, for each of the channel groups. In Table 29 can be observed that the significance for signal level and MER for channel 18 surpasses the 5% threshold which implies that the means of this measured variables at different heights are not significantly different. In the case of channel 30 and 40 occurs the opposite because the significance for the signal level and the MER falls under the 5% threshold which implies that mean of the results of at least one measuring height differs from the mean of the other heights.

In order to determine which is the group of data that differs from the others, after the analysis of variance is performed a Duncan test [24], that is designed to identify the pairs of means that differ from at least three groups. The procedure consists on arranging the means from high to low and contrast the highest mean with the lowest by comparing the difference between them with the product of the standard deviation and the critical values obtained from the Q distribution. If the difference of means is higher so the highest and lowest means are significantly different, the process continues with the second highest mean until all the means are compared with lowest mean or difference between means are lower than the product between the standard deviation and the Q value.

ANOVA

Channel aggrupation			Sum of Squares	df	Mean Square	F	Sig.
18	Level	Between Groups	455.799	3	151.933	1.753	0.158
		Within Groups	15252.449	176	86.662		
		Total	15708.248	179			
	MER	Between Groups	40.542	3	13.514	0.488	0.691
		Within Groups	4594.918	166	27.68		
		Total	4635.46	169			
30-49	Level	Between Groups	1826.669	3	608.89	10.279	0
		Within Groups	21088.318	356	59.237		
		Total	22914.987	359			
	MER	Between Groups	113.953	3	37.984	2.915	0.035
		Within Groups	2971.413	228	13.033		
		Total	3085.366	231			

Table 29. Analysis of variance for the variable height.

In the following tables can be observed the aggrupation performed by the Duncan test for each variable, in the case of channel 18 is observed that for both variables all the heights are considered one group, implying that there is no difference between the means of the results at each of the measuring heights.

In the case of channel 30 and 49 can be observed that for the signal level is established that the results can be divided in three groups, 2 m-4 m, 4 m-6 m and 8 m. Which means there is a relation between the results at 2m with the results at 4 m, meanwhile the results at 4 m are related with the results at 6m but there is no relation between the results at 2 m with the results at 6 m, and finally the results at 8m differ from the results of all the other heights. For the MER is established that the results can be divided in two groups, 2 m-4 m-6 m and 6 m-8 m. Which means there is a relation between the results at 8 m only with the results at 6m but the results at 6m are related to the results at 2 m and 4 m.

Channel aggrupation=18

Duncan[a]

Height	N	Subset for alpha = 0.05
		1
4	45	68.8892
2	45	69.0878
6	45	71.0298
8	45	72.7954
Sig.		0.07

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 45.000.

Table 30 Homogeneous subset for signal strength of channel 18.

Channel aggrupation=30-49

Duncan[a]

Height	N	Subset for alpha = 0.05		
		1	2	3
2	90	53.1385		
4	90	54.8239	54.8239	
6	90		56.8934	
8	90			59.1507
Sig.		0.143	0.072	1

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 90.000.

Table 31. Homogeneous subset for signal strength of aggrupation of channels 30-49.

Channel aggrupation=18

Duncan[a,b]

Height	N	Subset for alpha = 0.05
		1
4	44	23.86876081
6	42	24.57683653
8	39	24.63512525
2	45	25.21540469
Sig.		0.29

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 42.373.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 32. Homogeneous subset for MER of channel 18.

Channel aggrupation=30-49

Duncan[a,b]

Height	N	Subset for alpha = 0.05	
		1	2
2	63	17.62449602	
4	61	17.74067706	
6	54	18.88557099	18.88557099
8	54		19.24032291
Sig.		0.077	0.598

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 57.717.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 33. Homogeneous subset for MER of aggrupation of channels 30-49.

Glossary

A list of all acronyms and what they stand for.

ABNT	Brazilian Association of Technical Norms
AC	Auxiliary Channel
AC	Audio Compression
ARIB	Association of Radio Industries and Businesses
ATSC	Advanced Television Systems Committee
BER	Bit Error Rate
COFDM	Coded orthogonal frequency division multiplex
DiBEG	Digital Broadcasting Expert Group
DTT	Digital Terrestrial Television
DTTB	Digital Terrestrial Television Broadcasting
DTV	Digital Television
DVB	Digital Video Broadcasting
HDTV	High Definition Television
ISDB-T	Integrated Services Digital Broadcasting-Terrestrial
ISDB-Tb	Integrated Services Digital Broadcasting-Terrestrial built-in
LDTV	Low Definition Television
MER	Modulation Error Rate
MICITT	Ministry of Science, Technology and Telecommunications
MPEG-2	Moving Pictures Experts Group-2
PNAF	National Frequency Allocation Plan
RMSE	Root-Mean-Square Error
SBTVD	Brazilian System of Digital Television
SDTV	Standard Definition Television
SUTEL	Superintendence of Telecommunications
SNGME	National System of Gestion and Monitoring of Spectrum
TMCC	Transmission Multiplexing Configuration Control
TOV	Threshold of Visibility
UHF	Ultra High Frequency
VSB	Vestigial Sideband Modulation