Field Trials Based Planning Parameters for DVB-T2 Indoor Reception

Cristina Regueiro, Member, IEEE, Unai Gil, Member, IEEE, Manuel Velez, Member, IEEE, Inaki Eizmendi, Member, IEEE, Pablo Angueira, Senior Member, IEEE

Abstract—This paper presents the field trials carried out in Bilbao (Spain) for testing and analyzing the performance of the DVB-T2 indoor (fixed and pedestrian) reception. Test services with different DVB-T2 and T2-Lite configuration modes have been broadcasted and indoor measurements have been carried out. As a result, SNR threshold values for DVB-T2 indoor reception have been obtained. These values update those provided by previous studies and are also valid for planning tools to be used by broadcasters in the development of DVB-T2 networks.

Index Terms—DVB-T2, T2-Lite, field trials, indoor portable reception, SNR Threshold, time variability, location variability.

I. INTRODUCTION

The recent developments of the information technologies and the new audiovisual contents have contributed to the need of setting new broadcasting standards. For this reason, digital broadcasting standards have evolved to a second generation. In the case of DTTB, the DVB project developed a second generation digital terrestrial television named DVB-T2 standard [1], first standardized in September 2009. Although DVB-T2 primarily targets outdoor fixed reception (rooftop antennas), its reception is also feasible in portable or mobile indoor and outdoor environments [2]-[4], due to the large amount of possible configurations in comparison with its predecessor DVB-T.

Furthermore, in April 2012 the standard was updated, including a new profile named T2-Lite, optimized for mobility. This new profile can be combined with another T2 profile using the Future Extension Frames (FEF) in a mixed configuration mode. In this case, two different DVB-T2 signals with separated parameters, such as the FFT size, the fraction of guard interval or the pilot pattern, are considered. Besides, each DVB-T2 signal can include several services with different robustness schemes, using the multiple Physical Layer Pipe (PLP) feature [1]. Thus, several types of services can be provided at once in the same radiofrequency channel.

DVB-T2 is therefore valid to transmit high capacity services (HD, 3D [5], UHD) to be received with fixed outdoor rooftop antennas while low capacity but more robust services could be received in portable or even mobile receivers (tablets, smart-phones, laptops...) in both indoor and outdoor scenarios. Up to now, several studies have analyzed the quality of the DVB-T2 and DVB-T2-Lite digital signals in outdoor fixed and mobile scenarios [3]-[8]. However, the quality of the reception in portable indoor scenarios has not been sufficiently studied. This scenario is heavily influenced by multipath, due to the obstacles such as walls and windows [9][10]. Besides, there may also be furniture or even people moving around the receiver, which increase the signal variability influencing the reception quality [11][12]. For this reason, it is necessary to characterize the reception of DVB-T2 signals in indoor environments. For this purpose, a measurement campaign was carried out in several indoor locations in the city of Bilbao (Spain).

The signal reception characterization can be expressed by means of minimum Signal to Noise Ratio (SNR) threshold. This result could be taken into account by broadcasters or in planning tools as reference values. Besides, it is important to establish a DVB-T2 indoor performance methodology that takes the time and spatial signal variations into account [13][14]. Furthermore, it is also important to obtain SNR threshold based on laboratory measurements. Comparing these results with those obtained in the field trials, it is possible to decide which is the most appropriate channel model to simulate the indoor scenarios.

The paper is organized into 6 sections. Section II includes the main objectives of this study. Section III describes the measurement campaign while Section IV defined the processing methodology carried out to obtain the signal performance. Finally, Section V includes the studies and analysis carried out following the methodology defined in Section IV and shows the obtained results. The main conclusions are listed in Section VI.

II. OBJECTIVES

The main objective of this paper is to characterize the reception of the DVB-T2 signals in indoor environments based on field trials so as to determine the required minimum signal to noise ratio (SNR) for a correct indoor portable reception. These results could be considered as reference information that could be taken into account by future network planners to establish the necessary transmitted power [15]. To this end, the following studies have been considered.

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• Define suitable configuration modes to receive high quality services in fixed outdoor and low capacity but high robustness services in portable indoor reception.
• Define the correct reception criterion for both fixed and pedestrian indoor reception.
• Analyze the time variability of the received signal in each measured indoor scenario.
• Analyze the location variability of all the measurements.
• Define the methodology to obtain the SNR threshold based on the three previously defined studies (correct reception criterion, time and location variability).
• Obtain reference SNR threshold values in typical indoor channels (both fixed and pedestrian) based on laboratory tests and applying the same methodology to obtain the SNR threshold described in the previous point.
• Compare the field trials based SNR thresholds with those obtained in the laboratory for the emulated channels.

III. MEASUREMENT CAMPAIGN

A. Configuration parameters

One mixed DVB-T2-Base and T2-Lite signal with multiple PLPs was defined and tested. This signal includes two profiles by means of the FEF feature. The main parameters of each tested configuration mode of the mixed signal are shown in Table I.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Frame length (ms)</th>
<th>FFT / IG / PP</th>
<th>LDPC FEC length</th>
<th>MOD-COD(*)</th>
<th>Capacity (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>209.7</td>
<td>32k /1/12/PP7</td>
<td>64 K</td>
<td>256QAM 2/3</td>
<td>23.0</td>
</tr>
<tr>
<td>Lite</td>
<td>249.6</td>
<td>8k /1/16/PP4</td>
<td>16 K</td>
<td>QPSK 1/3</td>
<td>1.1</td>
</tr>
</tbody>
</table>

B. Experimental Network

The “Banderas” transmission center, shown in Figure 1, was used to cover the urban core of the city of Bilbao, in the north of Spain. It is located on a hill of about 216 meters high and about 3 km far from the city centre of Bilbao. Bilbao is a city with an urban centre with medium altitude of around 8m over the sea level. The most of the buildings are between 5 and 10 floors with very few skyscrapers.

The transmission equipment consisted of:
• DVB-T2 and DVB-T2-Lite modulator that generated the signal at Intermediate Frequency (IF).
• Frequency converter and pre-amplifier that shifted the IF signal to the RF frequency channel 48 (690 MHz) and amplified it to achieve the required level power to input the power amplifiers.
• Power amplifier that provided a total power level of 300W.
• Computer to configure the DVB-T2 configuration options (modulator) and the transmission power levels (up-converter and main amplifier).
• Radiating system in vertical polarization with a two panel array (16 dBi maximum gain), providing a 5kW ERP.
The DVB-T2 modulator and the up-converter were connected to the computer, while the computer and the amplifier were directly connected to the broadcaster’s internal network. Thus, accessing the transmission internal network through a Virtual Private Network (VPN) by means of a Remote Desktop application, the equipment was remotely controlled. Besides, a fast configuration of all the parameters associated with the transmitted signals was allowed.

Figure 2 shows all the signal and control connections in the transmitter.

C. Reception System

The reception system, shown in Figure 3, was based on an on-line IQ signal recording for posterior off-line laboratory processing, which provided great flexibility [18].

The reception system consisted of a 2 dBi vertical monopole tuned to the transmission frequency of 690 MHz and connected to a channel filter, set to channel 48, to prevent other emissions interfere with desired signal measurement. The received signal was recorded using an IQ recorder equipment in a SSD (solid-state drive) hard disk as baseband IQ samples for a posterior off-line processing stage. Besides, during the measurements, information related to the environment was manually recorded (location, height, type of building, type of room, presence of furniture or people around, presence of windows in the room…) in order to obtain information about the reception environment.

D. Measurement locations

The measurement campaign was carried out in 10 buildings inside the city of Bilbao. Figure 4 shows a map of Bilbao with the location of the transmitter marked with a yellow triangle and the reception locations marked with purple circles.

Fixed and pedestrian indoor scenarios were measured. In a fixed indoor scenario the receiver is static although there could be people moving around it. Furthermore, in a pedestrian indoor scenario the receiver moves at near 3 km per hour while there could also be people moving around it.

Eight of the locations were housing buildings. Measurements were carried out in every room in the house, including rooms with and without windows, at different floors and with different wall materials. In addition, data was also recorded in common spaces of the building (landings, as well as vestibules). Figure 5 shows an example of this kind of scenarios. The other two locations were inside public buildings (university and primary school) with many people inside. All these locations have been considered as a representative sample of indoor environments.

Table II summarizes all the main features of the measured locations. Altogether, 107 different fixed locations and 137 different pedestrian routes were measured in indoor environments.
The first column indicates each location number, while Column 2 indicates the floor in the building. Column 3 shows the number of fixed measurements recorded in rooms inside its building. Column 4 indicates the number of pedestrian measurements carried out inside each building.

### E. Recording times

In order to define appropriate recording times in each type of measurements (fixed and pedestrian), different criteria were applied.

In the case of fixed reception in indoor scenarios, several measurements with different recording times were previously carried out in the same locations with and without people moving in the surrounding area. Analyzing the signal power along the different tested recording times, it has been checked that the power time variation is almost the same in all the cases (the standard deviation is always lower than 0.25 dB). For this reason, it is not necessary to record the received signal during long periods of time. Thus, 15 seconds recording time has been considered representative enough for the signal power time variability in indoor environments.

In the case of pedestrian reception in indoor environments, the recording time has been chosen considering the typical size of a room in a housing building. Taking into account that routes of around 8m length have been carried out inside each room and that 3 km per hour is a typical speed of a person walking in an indoor environment, measurements during 10 seconds are considered to define a route inside a room.

## IV. PROCESSING METHODOLOGY

All the data stored on hard disks during the field trials were afterwards processed in the laboratory with a professional receiver in order to obtain the performance results. The receiver is a software implementation developed for signal analysis by TSR research group of the University of the Basque Country [19]. It implements the whole reception chain, from synchronization to PLP extraction, providing detailed measurements of the main parameters of the recorded signal. Figure 6 shows the off-line components of the measurement system scheme.

![Figure 6. Off-line measurement system](image)

The off-line processing generated multiple files with information about the quality of the received signal. The most relevant were the error rate for each Forward Error Correction (FEC) block in a DVB-T2 frame and the SNR per symbol in a DVB-T2 frame.

### A. Threshold Criterion

The first step in order to make a performance study of the measured DVB-T2 configuration mode in indoor environments is based on establishing the correct reception threshold criterion to be applied.

The DVB-T2 standard sets the threshold criterion for DVB-T2 signal correct reception in getting to the Quasi Error Free (QEF) point. This point is reached when the BER is lower than or equal to \(10^{-7}\) after Low Density Parity Check (LDPC). However, the limited measurement time prevents from obtaining the QEF point. That is why the threshold criterion was based on a FEC Blocks Error Rate (FBER) [20], which is defined as the ratio of erroneous FEC blocks received during an observation period established in a T2-frame time. Therefore, the representative value of SNR has been obtained as the median value per T2-frame.

In several locations the received power level was high and consequently the reception was always correct and no erroneous FEC block was received. In these locations Additive White Gaussian Noise (AWGN) can be added to the entire signal so as to decrease the SNR value until several erroneous FEC Blocks appear [18]. Therefore, the off-line processing includes the addition of increasing noise power to every recorded signal so as to find the SNR threshold in each case. The limit in the noise power level is reached when erroneous FEC Blocks appear in every recorded signal for any of the configuration parameter sets.

![Figure 7](image)

Figure 7 depicts an example of the relation between SNR and the FBER percentage per T2-frame in an indoor location for one PLP. FBER values (also considering different additional noise power levels in the specific location), are represented with crosses. As it can be seen, the drop in the relation between the error rate and the SNR of the LDPC codes is very sharp, which means a change from correct reception to signal loss in just a few tenths of decibel in the SNR value [21].
Figure 7. SNR vs FBER

The FBER percentage values can be easily approximated to a straight line. Thus, a linear approximation has been applied (shown in Figure 7 as a blue line) so as to obtain an instantaneous SNR threshold for each measured location based on the FBER vs SNR relation per T2-frame.

The selected FBER threshold criterion is based on the limit of the percentage of frame length time that can be erroneous. Taking into account that having a coverage of 99% time is considered as good reception in mobility [22], a threshold criterion based on having 1% FBER (in other words, having 99% of T2-frame time correct) has been established.

B. Methodology for Obtaining the SNR threshold

The data obtained from the off-line processing with the professional receiver (FBER and SNR per T2-frame) is the starting point for the performance analysis. The methodology to obtain the reference SNR threshold in fixed and pedestrian indoor scenarios is shown in Figure 8.

The starting point calculates the threshold criterion based on 1% FBER to every recorded signal (both in fixed and pedestrian measurements), obtaining an instantaneous SNR threshold per location/route. These instantaneous SNR thresholds should be referred to 50% of time as in planning tools. In this case, each location is mainly characterized with its median SNR or median power level in the time domain, which is the information usually used by broadcasters. Thus, the instantaneous thresholds referred to 50% time (Step 1 in Figure 8) are obtained.

The second step carries out a statistical study of the instantaneous SNR threshold from Step 1, obtaining the median value of the instantaneous SNR thresholds of each locations/routes ($SNR_{inst}$). Thus, the SNR threshold for the 50% of the time and 50% of the locations is obtained (Step 2 in Figure 8).

In digital services, it is typical to cover the 99% time [22], so it is important to determine the signal variation and obtain the SNR threshold value for this percentage of measured time. For this reason, the following step (Step 3 in Figure 8) analyzes the time variability of the SNR in each location/route so as to obtain the necessary time correction factor between covering the 50% and 99% of the signal time in each location/route. Next, a statistical study of the time correction factors of each location/route is done in order to obtain a generic and common time correction factor (TCF) to cover the 99% signal time in an indoor environment. This common time correction factor is applied to the SNR threshold for 50% time and 50% locations from Step 2 resulting in a SNR threshold value for the 99% time and 50% locations.
The final step (Step 4 in Figure 8) lies in making a statistical study of the instantaneous SNR threshold values for all the locations from Step 1 so as to obtain the location correction factor (LCF) to cover the 95% of the locations. The LCF is applied to the SNR for 99% time and 50% locations from Step 3 resulting in a unique SNR threshold value that covers the 95% of the locations [21]. This threshold value is an overall SNR threshold value for the 99% of the time and the 95% of the locations.

Taking all above into consideration, the SNR threshold in indoor reception is given by equation (1):

\[
SNR_{\text{final}}(dB) = SNR_{\text{initial}}(dB) + TCF(dB) + LCF(dB)
\]

Equation (1) summarizes that the SNR threshold (SNR_{\text{final}}) per each configuration parameters set is initially given by the SNR for 50% time and 50% locations (SNR_{\text{initial}}) obtained by means of 1% FBER criterion (Step 2). This value has to be updated with the Time Correction Factor (TCF) (Step 3) and the Location Correction Factor (LCF) (Step 4) so as to cover the 99% of the time and the 95% of the locations.

C. Laboratory Reference values

Apart from the results obtained in the field trials, some laboratory measurements were also carried out in order to obtain the reference values for indoor reception with emulated channel models. Rice and Rayleigh theoretical channels [23] will be considered for fixed indoor reception. Additionally, it is shown in [24] that a specific channel model was needed in order to simulate the pedestrian indoor reception. This was the Pedestrian Indoor (PI) [25] channel model. Besides, the ITU also proposed two channel models intended for pedestrian indoor reception, Indoor Office A (IOA) and Indoor Office B (IOB) [26].

Figure 9 describes the laboratory measurements set-up using the same receiver as in the field trials but emulating the channels by means of a hardware channel emulator. The methodology applied is the one described subsection B but considering that the time variation is null (TCF = 0 dB) for the channel models considered for fixed indoor reception, while the spatial variation is null (LCF = 0 dB) for every simulated channel model.

V. STUDIES AND RESULTS

A. SNR Threshold for 50% time and 50% locations

Applying the 1% FBER criterion for every measured location/route during the 15 seconds recording time in fixed reception and during 10 seconds in case of pedestrian reception, the instantaneous SNR threshold values per location/route are shown in Figure 10 for fixed reception and in Figure 11 for pedestrian reception (Step 1 in Figure 8). The straight lines show the median instantaneous SNR value for each DVB-T2 configuration mode considering all the measured locations.

Numbers in the abscissa axis of Figure 10 and Figure 11 indicate the amount of measurement locations on which the threshold situation has been reached for each DVB-T2 configuration parameters set. This number depends on the robustness of the configuration parameters, showing in general fewer locations for the least robust configuration mode (256QAM) on which it was not possible to reach the threshold situation because it was directly received with more errors than those of the 1% FBER criterion.

Furthermore, although the highest number of measurement locations should be for the most robust configuration mode (QPSK 1/3), the situation is different. This is because it is necessary to establish a tradeoff between the additional processing time required for reaching the threshold situation in new locations and the number of measurements that are statistically representative. Thus, the statistical analysis results will be the same with a higher number of measurements.
fixed and pedestrian scenarios. These results are important due to the fact that they are the reference values broadcasters take into consideration and are also used in network planning tools. The results included in Table III are the SNR thresholds for 50% time and 50% locations (Step 2 in Figure 8) and its variance, obtained from the previous results in dB.

As it can be seen, the difference of the median value of the instantaneous SNR threshold between pedestrian and fixed scenarios ranges between 2.2 and 2.7 dB depending on the configuration mode. However, the variance is mainly the same in pedestrian as in fixed scenarios. This shows that the receiver movement has less influence on the SNR threshold than the changing surrounding environment. For this reason, the variance in static and pedestrian reception is similar because it is only affected by the surrounding scenario. The variance for the 256QAM parameters set is higher, especially in case of pedestrian reception. The reason for this high value may be the high SNR threshold of this configuration as it is not suitable for indoor reception.

### B. SNR Threshold for 99% time and 50% locations

The instantaneous SNR per location for the 50% time obtained in Subsection A (Step 2) has to be updated to the 99% of the signal time [22]. For this purpose, the time variability of the SNR in each location has to be analyzed to obtain the time correction factor [27].

Figure 12 shows an example of the process of obtaining the time correction factor for the 99% time in one location/route. “D99” is the difference between the SNR exceeded for 99% and 50% time. In other words, the difference between the SNR value that is exceeded during the 99% of the time and during the 50% of the time. “D99” is the time correction factor that should be applied to the SNR threshold for the 50% time in each location/route (from Step 1) because of the time variability of the signal.
In addition to obtaining the time variability correction factor for the 99% of the time (“D99”) as it is typical in digital services, other time percentages can be also studied. The main percentages of time to consider besides 99% are 100% (“D100”) and 95% (“D95”), because they are typical percentages to consider for the time variability [24]. The process to obtain them is the same as for “D99” but with different percentages of time.

Table IV and Table V show the main statistical features of the time correction factors (TCF) (“D100”, “D99” and “D95”) in fixed and pedestrian indoor locations, respectively.

**TABLE IV**
TIME VARIABILITY CORRECTION FACTOR (TCF) (dB): STATISTICAL ANALYSIS IN FIXED SCENARIOS

<table>
<thead>
<tr>
<th>Statistical Features</th>
<th>100%</th>
<th>99%</th>
<th>95%</th>
<th>90%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Time Correction Factor</td>
<td>4.9</td>
<td>4.6</td>
<td>3.5</td>
<td>2.3</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**TABLE V**
TIME VARIABILITY CORRECTION FACTOR (TCF) (dB): STATISTICAL ANALYSIS IN PEDESTRIAN SCENARIOS

<table>
<thead>
<tr>
<th>Statistical Features</th>
<th>100%</th>
<th>99%</th>
<th>95%</th>
<th>90%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian Time Correction Factor</td>
<td>11.7</td>
<td>10.6</td>
<td>8.2</td>
<td>7.5</td>
<td>5.0</td>
</tr>
</tbody>
</table>

In fixed scenarios, as it can be seen in Table IV, the differences between “D100” and “D99” are always lower than 0.1 dB while the differences between “D99” and “D95” can be up to 0.7 dB. Equally, in pedestrian reception, the differences between “D100” and “D99” are always lower than 0.1 dB but these differences increase up to 1.8 dB when comparing “D99” with “D95”. This means that the time variability correction factor for the 99% time (“D99”), which is the typical one for digital services, is restrictive enough without involving huge degradation in the TCF in comparison with other time percentages (always lower than 0.1 dB).

The statistical features of “D99” in Table IV and Table V show that 100% and 99% percentiles are too restrictive with increments of around 1.2 dB in fixed reception and between 2.5 and 3.6 dB in pedestrian reception in comparison with 95%. Considering that 50% and 75% percentiles are not restrictive enough, the 95% percentile statistical feature, which is considered as good reception [22], is the one to consider for the time variability correction factor in both fixed and pedestrian indoor scenarios.

Taking all into consideration, the time correction factor in a fixed indoor environment is established in 3.5 dB while it increases up to 8.1 dB in case of pedestrian indoor scenarios. This fact shows that the time variability of the received signal in indoor environments has more influence on the pedestrian than on the fixed reception. The receiver movement in pedestrian indoor scenarios in comparison with fixed scenarios means an increment of 4.6 dB in the TCF for covering the 99% time.

The SNR thresholds values for 50% time and 50% locations from Step 2 are updated with this time correction factor to cover the 99% time. The results are summarized in Table VI, resulting in SNR thresholds for 99% time and 50% locations (Step 3 in Figure 8).

**TABLE VI**
SNR THRESHOLD FOR 99% TIME AND 50% LOCATIONS (dB)

<table>
<thead>
<tr>
<th>Fixed Scenario</th>
<th>Pedestrian Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>Median</td>
</tr>
<tr>
<td>Base: 256QAM 2/3</td>
<td>24.2</td>
</tr>
<tr>
<td>Lite: QPSK 1/2</td>
<td>5.0</td>
</tr>
<tr>
<td>Lite: QPSK 1/2</td>
<td>6.5</td>
</tr>
<tr>
<td>Lite: 16QAM 1/2</td>
<td>11.3</td>
</tr>
</tbody>
</table>

As it can be seen, the median value of the SNR threshold for 99% time in pedestrian scenarios increases between 6.7 and 7.3 dB in comparison with the fixed SNR thresholds, depending on the configuration mode. Besides, the variance remains as in Subsection A, as the time correction factor applied is common to all the DVB-T2 configurations.

C. **SNR Threshold for 99% time and 95% locations**

Once the time variability correction factor (TCF) has been assessed, the location variability has also to be established [28]. The study of the location variability depends on the specific configuration parameters set because it is based on a study of the SNR thresholds in different locations.

The instantaneous SNR threshold from Step 1 is different in each measured location and a statistical study of the location variation has to be carried out. Therefore, the main statistical features of the location variability (75% and 95% percentile values) have been obtained for each configuration mode.

A good reception is supposed if the 95% of the locations are covered, while an acceptable reception is in case of 75% [26]. For this reason, “D95” and “D75” are obtained. “D95” is the difference between the SNR for 95% and 50% locations, while “D75” is the difference between the SNR for 75% and 50% locations. These are the location correction factors that should be applied to the SNR threshold for the 99% time and 50% locations (from Step 3) because of the location variability of the signal.
Figure 15 and Figure 16 show the Cumulative Distribution Function (CDF) for instantaneous SNR thresholds (Step 1) depending on the locations/routes for fixed and pedestrian reception, respectively. The dotted black lines and their associated values are the SNR threshold for the 50% time and for typical percentiles of locations, such as 50%, 75% (acceptable reception) and 95% (good reception). For this reason, the location variability correction factors (LCF)”D95” and “D75” are shown in Figure 15 and Figure 16 in blue for one exemplifying configuration parameters set. These LCF should be applied to the SNR threshold from Step 3 and are different for each configuration mode.

Table VII shows the location correction factors (LCF) “D75” and “D95” for both fixed and pedestrian reception for each configuration mode.

<table>
<thead>
<tr>
<th>TABLE VII</th>
<th>LOCATION VARIABILITY CORRECTION FACTOR (LCF) (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed Scenario</td>
</tr>
<tr>
<td></td>
<td>“D95”</td>
</tr>
<tr>
<td>Base: 256QAM 2/3</td>
<td>2.5</td>
</tr>
<tr>
<td>Lite: QPSK 1/3</td>
<td>1.9</td>
</tr>
<tr>
<td>Lite: QPSK 1/2</td>
<td>2.4</td>
</tr>
<tr>
<td>Lite: 16QAM 1/2</td>
<td>2.4</td>
</tr>
</tbody>
</table>

As it can be seen in Table VII, the more robust the DVB-T2 configuration is, the lower influence on the location variability is presented both fixed and pedestrian reception. As all the configuration modes were measured at once, the changes in the measuring location/route, and the consequent change on the propagation channel, has an increasing influence according to the decreasing configuration robustness. It has been previously demonstrated [29], that the higher the code rate robustness is, the propagation channel has lower influence on the required SNR spatial variability. For this reason, modes with the same code rate present similar variability results.

As it can be seen in Figure 15 and Figure 16, the slope of the CDF curve for each configuration parameters set indicates the influence of the location variability in each case. If the curve was perfectly vertical, all the measured locations/routes would have the same instantaneous SNR threshold for 50% time and the location correction factor in these cases would be null. However, different measured points have different instantaneous SNR threshold for 50% time, and for this reason, there is a slope in the CDF curve. The higher the slope is, there is more influence of the location variability on the SNR threshold.

As it can be seen in Table VII, the more robust the DVB-T2 configuration is, the lower influence on the location variability is presented both fixed and pedestrian reception. As all the configuration modes were measured at once, the changes in the measuring location/route, and the consequent change on the propagation channel, has an increasing influence according to the decreasing configuration robustness. It has been previously demonstrated [29], that the higher the code rate robustness is, the propagation channel has lower influence on the required SNR spatial variability. For this reason, modes with the same code rate present similar variability results.

All in all, it is not possible to establish a common and unique location variability correction factor to cover higher percentages of locations and thus, the location variability has to be considered individually for each configuration parameters set.

In fixed reception, considering an increment from 50% to 75% on the location percentage, increments on the SNR threshold between 0.4 and 1.6 dB should be considered. In case of covering 95% of the locations, the increment on the SNR threshold is between 1.9 and 2.5 dB. In case of pedestrian reception, the increment to cover 75% locations is between 0.4 and 1.0 dB, while the location correction factor to cover 95% locations, depending on the configuration, varies from 1.3 and 6.4 dB. This last high LCF is for the 256QAM configuration mode, which presents a high variance on the SNR threshold for 99% time, due to the fact that its high instantaneous SNR threshold is not appropriate for pedestrian indoor reception. The results are similar to those proposed in [28].

If fixed and pedestrian LCF are compared, it can be seen that the location variability for pedestrian reception is mainly equal or even lower than in fixed scenarios. This might be because the receiver movement may counteract some of the changing environment effects on the reception, obtaining a similar or even lower LCF.

Anyway, from Table VII, the “D95” location correction factor, which is considered as a “good” reception [26], is the one that should be applied to the SNR threshold for 99% time from Step 3. Thus, the SNR threshold for 99% time and 95% locations obtained after applying all the processing methodology for both fixed and pedestrian indoor scenarios.
are obtained (Step 4 in Figure 8). These SNR thresholds can be a reference value to be considered for fixed and pedestrian indoor reception (with the exception, again, of the 256QAM configuration, whose high SNR threshold are not appropriate for pedestrian reception).

Table VIII and Table IX summarize the main DVB-T2 planning parameters that can be considered as reference for broadcasters and can be taken into account in planning tools, for both fixed and pedestrian indoor reception. The first column is the median SNR threshold (SNR for 50% time and 50% locations) (Step 2 in Figure 8). The second and third columns are the TCF (Time Correction Factor) and LCF (Location Correction Factor) respectively. The forth column is the SNR threshold for 99% time and 95% locations (Step 4 in Figure 8).

<table>
<thead>
<tr>
<th>Table VIII</th>
<th>DVB-T2 Planning Parameters in Fixed Indoor Scenarios (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed Scenarios</strong></td>
<td>SNR</td>
</tr>
<tr>
<td>Base: 256QAM 2/3</td>
<td>20.7</td>
</tr>
<tr>
<td>Lite: QPSK 1/3</td>
<td>3.5</td>
</tr>
<tr>
<td>Lite: QPSK 1/2</td>
<td>3.0</td>
</tr>
<tr>
<td>Lite: 16QAM 1/2</td>
<td>7.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table IX</th>
<th>DVB-T2 Planning Parameters in Pedestrian Indoor Scenarios (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pedestrian Scenarios</strong></td>
<td>SNR</td>
</tr>
<tr>
<td>Base: 256QAM 2/3</td>
<td>23.3</td>
</tr>
<tr>
<td>Lite: QPSK 1/3</td>
<td>3.7</td>
</tr>
<tr>
<td>Lite: QPSK 1/2</td>
<td>5.7</td>
</tr>
<tr>
<td>Lite: 16QAM 1/2</td>
<td>10.1</td>
</tr>
</tbody>
</table>

As it is shown in Table VIII and Table IX, the location variability influence on the SNR threshold is lower than the time variability in both scenarios. This is because the indoor propagation channels (both fixed and pedestrian) are time variant but they are similar in every location.

Taking the 99% time and 95% locations requirements into consideration, the increment in SNR threshold between fixed and pedestrian indoor reception is between 6.2 and 6.5 dB with the exception of the 256QAM configuration mode (the increment increases up to 9.9 dB), which it is not ideal for indoor reception.

D. Comparison with reference values

The SNR threshold obtained for the fixed indoor reception (based on field trials) are compared with the Rice and Rayleigh channels, considering results based on laboratory measurements and the reference values included in the DVB-T2 implementation guidelines (IG) [23]. In pedestrian scenarios, the SNR threshold for indoor reception (based on field trials) is compared with the Pedestrian Indoor (PI) channel [24] and Indoor Office A (IOA) / Indoor Office B (IOB) [26] (based on laboratory measurements). In this case, there are no reference values in the DVB-T2 implementation guidelines.

The laboratory measurements were carried out following the same methodology as in the case of the field trials but without considering the Step 4 as the location variability is null (the emulated channel do not present this variability). In case of fixed reception (Rice and Rayleigh), the time variability is also null as the channel power is constant during the whole measured time. For this reason, in these cases, the time correction factor is also null and Step 3 in Figure 8 does not have to be applied. However, in pedestrian reception (PI, IOA and IOB), the channel power varies with the time and the corresponding TCF has to be obtained and applied (Step 3 in Figure 8). Indeed, “D99” for the PI propagation channel model during 10 seconds is 1.9 dB while this value increases up to 4.8 dB in case of IOA and 4.2 dB for IOB channel models.

Table X summarizes the comparison of the SNR threshold results in fixed indoor scenarios between reference values based on simulations (from the IG), laboratory measurements with typical fixed indoor propagation channel models and measured results based on field trials. As the SNR thresholds for theoretical fixed channel models are for 50% time and 50% locations (TCF and LCF are null), the SNR thresholds based on field trials considered to be compared are also for 50% time and 50% locations.

<table>
<thead>
<tr>
<th>Table X</th>
<th>SNR Thresholds in Fixed Indoor Scenarios (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reference value (IG)</strong></td>
<td>Laboratory measurements</td>
</tr>
<tr>
<td>Rice</td>
<td>Ray</td>
</tr>
<tr>
<td>Base: 256QAM 2/3</td>
<td>18.4</td>
</tr>
<tr>
<td>Lite: QPSK 1/3</td>
<td>-- (*)</td>
</tr>
<tr>
<td>Lite: QPSK 1/2</td>
<td>1.4</td>
</tr>
<tr>
<td>Lite: 16QAM 1/2</td>
<td>6.2</td>
</tr>
</tbody>
</table>

(*)--*: SNR Threshold reference values in IG do not exist for T2 Lite new code-rates

As it can be seen in Table X, the laboratory measurement results for Rice and Rayleigh channel models compared with the reference values from IG show the implementation losses of the receiver and the FBER criterion applied. These losses are slightly different depending on the DVB-T2 configuration parameters although its value remains always lower than 1 dB with independence of the channel model [30][31].
Comparing the SNR threshold values obtained from laboratory measurements and those obtained from field trials, it can be stated that the actual fixed indoor channel is similar to the Rayleigh theoretical channel model (with differences always lower than 0.5 dB). For this reason, it can be concluded that the Rayleigh channel model, which is usually considered to model the fixed indoor reception, is appropriate for emulating an actual indoor reception.

In case of pedestrian indoor reception, Table XI summarizes the comparison of the SNR threshold results in fixed indoor scenarios between reference values based on simulations (from IG), laboratory measurements with typical fixed indoor channel models and measured results based on field trials. As the SNR thresholds for theoretical fixed channel models are for 50% time and 50% locations (TCF and LCF are null), the SNR thresholds based on field trials considered to be compared are also for 50% time and 50% locations.

Comparing the SNR results for 50% time and 50% locations obtained from laboratory measurements and those obtained from field trials, it can be stated that the actual pedestrian indoor channel is similar to the IOA theoretical channel model, with differences lower than 0.3 dB (with the exception of the 256QAM configuration, where the high variability of the SNR threshold increases the differences up to 0.9 dB). However, the TCF factor in the actual pedestrian indoor scenario is much higher than that obtained in the laboratory for the three simulated channel models, with differences between 3.3 dB for IOA and 6.2 dB for PI. For this reason, the IOA channel model is the good estimation for obtaining the SNR threshold in pedestrian indoor scenarios but the time variability of the signal should be increased in 3.3 dB.

VI. CONCLUSIONS

The main contribution of this paper is the calculation of empirical thresholds for DVB-T2 and DVB-T2 Lite indoor reception on a real receiving scenario. The values described in this work here improve significantly some previous results based on simulations. These values are a good reference to be taken into account by broadcasters or in planning tools. For this purpose, a detailed methodology has been established and followed. This was based on three main phases: obtaining an instantaneous SNR threshold in each location/route; next, correcting the previous values considering the signal time variability and, finally, applying the location variability correction.

The paper has presented a thorough analysis of coverage location and time statistics, that have a significant impact in the network planning process. Table VIII and Table IX summarize the main DVB-T2 planning parameters for fixed and pedestrian indoor reception, respectively. This information includes SNR thresholds for 50% time and 50% locations (which are necessary in planning tools), time and location variability correction factors, and SNR thresholds for 99% time and 95% locations (which are the actual thresholds to achieve the required coverage percentages in digital services.

The differences in the SNR thresholds for 99% time and 95% locations for fixed and pedestrian reception are mainly due to the different time variability of the received signal between fixed and pedestrian reception which supposes approximately an increase of 3.5dB in fixed but 8.1dB in pedestrian indoor scenarios. These time variability correction factors are valid not only for DVB-T2 but also for other digital 8 MHz COFDM technologies in UHF band.

Furthermore, the location variability influence is lower than the time variability. In fixed scenarios the location correction factor value reaches up to 2.4 dB, while in pedestrian the value is mainly up to 1.7 dB (with the exception of 256QAM configuration which, as mentioned before, is not a valid configuration for indoor environments).

Taking all into account, the increment in the SNR threshold so as to allow the pedestrian indoor reception in comparison to just fixed indoor reception is mainly between 6.2 and 6.5 dB (reaching 9.9 dB in case of 256QAM).

Apart from that, a comparison between the SNR threshold obtained in the field and those obtained in the laboratory for suggested theoretical channel models has been presented in Table X and Table XI. It is suggested that the Rayleigh theoretical channel model perfectly fits the fixed indoor reception. In case of pedestrian reception, the IOA theoretical channel model is appropriate to model the pedestrian indoor reception. However, a time correction factor of 3.3 dB should be applied.

<table>
<thead>
<tr>
<th>Laboratory measurements</th>
<th>Field trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base: 256QAM 2/3</td>
<td>Base: 256QAM 2/3</td>
</tr>
<tr>
<td>Lite: QPSK 1/3</td>
<td>Lite: QPSK 1/3</td>
</tr>
<tr>
<td>Lite: QPSK 1/2</td>
<td>Lite: QPSK 1/2</td>
</tr>
<tr>
<td>Lite: 16QAM 1/2</td>
<td>Lite: 16QAM 1/2</td>
</tr>
<tr>
<td>50% / 50% TCF</td>
<td>50% / 50% TCF</td>
</tr>
<tr>
<td>10.0 / 10.0 TCF</td>
<td>10.0 / 10.0 TCF</td>
</tr>
<tr>
<td>20.9 / 22.4 TCF</td>
<td>22.3 / 23.3 TCF</td>
</tr>
<tr>
<td>2.9 / 3.4 TCF</td>
<td>4.2 / 5.7 TCF</td>
</tr>
<tr>
<td>8.0 / 10.2 TCF</td>
<td>10.1 / 11.0 TCF</td>
</tr>
</tbody>
</table>

TABLE XI
SNR_THRESHOLDS_IN_PEDESTRIAN_INDOOR_SCENARIOS (dB)

Comparing the SNR results for 50% time and 50% locations obtained from field trials and those obtained from laboratory measurements, it can be seen that the actual fixed indoor channel is similar to the Rayleigh theoretical channel model (with differences always lower than 0.5 dB). For this reason, it can be concluded that the Rayleigh channel model, which is usually considered to model the fixed indoor reception, is appropriate for emulating an actual indoor reception.
ACKNOWLEDGMENT

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Technical and human support provided by the ENBIDO partners is gratefully acknowledged.

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[27] ITU-R Recommendation P.1546-1 “Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz”.
[30] ITU-R Recommendation BS.1114-7 “Systems for terrestrial digital sound broadcasting to vehicular, portable and fixed receivers in the frequency range 30-3 000 MHz”.