DVB-T2 Performance in Presence of Multipath Laboratory Tests

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***Abstract*—This paper presents the results of laboratory tests carried out to study the performance of DVB-T2 in presence of multipath in fixed reception with rooftop antenna. The typical multipath cause in this scenario is a Single Frequency Network (SFN) reception.**

A range of relative levels and delays between the main path and one echo are tested to obtain the C/N requirements for each case. DVB-T2 supports a large number of options that can be chosen to optimize the system. Some of those options (Pilot Patterns, Guard Interval Fraction, Rotated Constellations, FFT sizes) are tested to evaluate their performance. The results are compared with the simulation results available in the implementation guidelines for the extreme cases of Gaussian channel (no echo) and 0 dB echo channel (main path and echo at same level).

***Index Terms*—DTV and broadband multimedia systems, Field trials and test results, Channel modeling and simulation, DVB-T2.**

I. Introduction

The new DVB standard for DTT (Digital Terrestrial TV), DVB-T2, achieves lower reception requirements than its predecessor DVB-T. One of the proposed scenarios for the use of this system is fixed rooftop antenna reception [1]. The system can provide high data rates at those conditions which allows, for example, the broadcasting of several HDTV programs.

In general the use of rooftop receiving antenna leads to a propagation channel that is classified as Gaussian or Ricean with low ripple. When Single Frequency Networks (SFN) are used this is not true any more and a propagation channel with large multipath level could be present.

Depending on a variety of factors, like distance between the transmission centers used for the SFN and the receiver, radiated power, directivity of the antennas, angle of reception of different signals and so on, the delay between paths and their relative level can take different values. In real situations the directivity of the receiving antenna enforces the main path and it is not usual the presence of other paths of similar amplitude. Only when all the transmitters are in the same orientation severe multipath will be produced. In this study the simplest case with only two paths is considered.

The aim of this work is to test the performance of DVB-T2 receivers when such multipath is present. To do this, the C/N retirements for error free image reception are obtained for different delays and echo levels, from Gaussian channel to 0 dB echo. Similar studies have been published for DVB-T like in [2]. The DVB-T2 signal configuration options that can have some influence in the receiver performance when multipath is present are tested.

TABLE I
Default DVB-T2 configuration

FFT Size	GIF	BW	Pilot Pattern	Ext. Mode	QAM	Rotated Const.
32K	1/128	8 MHz	PP7	Yes	256	Yes

Code Rate	PAPR Reduct.	LDPC Size	Number of PLPs	TI Length	TI Type	Input Format
3/5	No	64800	1	3	1 T2 Frame	TS HEM

II. Configuration Options

The DVB-T2 standard [3] defines a number of configuration options that make the system suitable for different uses, from low data rate mobile services, to HDTV program broadcasting in fixed reception. This second scenario is the case tested in this study. The set of parameters to be tested is narrowed when selecting this kind of reception, for example mainly the higher constellation orders (64 and 256 QAM) are tested. The same happens with the FFT sizes, in this case 8K, 16K and 32K are tested with special emphasis in 32K. Although this way the number of possible combinations is reduced, it is still too large to test all of them, so the influence of one configuration parameter is tested while keeping the same value for some other parameters.

In order to specify the main configuration parameters used for each test a default configuration is defined with the parameters of Table I, and only the changes are specified in each test.

III. Tested Channels

The tested channel is formed by two static paths, the relative amplitude and delay are changed to have an echo at fixed delay, like in a SFN configuration. The maximum tested delay depends on the Guard Interval (GI) duration. The delay is varied from 0.1 up to 1.1 times the GI duration. The relative amplitude of the second path is adjusted form 15 dB to 0 dB. The 0 dB echo channel, as defined in [1] is tested too. This includes a frequency shift of 1 Hz. Gaussian channel is also measured as reference.

IV. TEST SEP-UP

A PC card DVB-T2 modulator is used as signal source. This card also implements a channel simulator and an AWGN generator. The delay and amplitude of the paths and the noise level can be adjusted to simulate the different defined profiles and to obtain the minimum C/N level at which the signal is error free demodulated for 30 seconds (C/N_{min}) by a commercial Set Top Box (STB). The C/N value is adjusted in 0.1 dB steps, so this is the resolution in all the measurements.

In same cases the STBs decode the signal after a long synchronization time, if this time is longer than 10 seconds the measurement is not considered as error free reception.

Some tests have been done using four different brand commercial DVB-T2 receivers, all of them STBs. As the results of these tests show the same performance of the receivers, the majority of the tests have been done using only one STB.

V. RESULTS

In this section the results of the measurements are presented organized in several subsections. In the first and second subsections the results for a Gaussian channel and 0 dB echo channel as defined in [1] are presented and compared with the simulated values also provided in the same document and the requirements for receivers according to NorDig [4] . In the other subsections the influence of a particular configuration option or a channel parameter is tested.

A. Gaussian Channel

These measurements are performed without channel simulation, only AWGN is added. The DVB-T2 configuration is the default one (Table I) with the following changes:

- Constellations: 64 and 256 QAM
- Rotated Constellations: Used and not used.
- Code rates: All code rates from 1/2 to 5/6.
- GIF and pilots patterns: 1/128, PP7 and 1/16, PP4.

The results of the measurements, the simulated values according to [1], and the NorDig requirements are summarized in Table II.

TABLE II
SIMULATED AND MEASURED C/N_{min} FOR GAUSSIAN CHANNEL

QAM	CR	Impl. Guid.$^{\alpha}$	NorDig	1/128 GIF, PP7 N.R	1/128 GIF, PP7 R	1/16 GIF, PP4 N.R	1/16 GIF, PP4 R
64	1/2	9.9	13.0	11.8	11.9	11.8	11.8
64	3/5	12.0	14.8	13.5	13.4	13.5	13.5
64	2/3	13.5	16.2	14.8	14.8	14.8	14.8
64	3/4	15.1	17.7	16.4	16.4	16.4	16.4
64	4/5	16.1	18.7	17.5	17.4	17.5	17.5
64	5/6	16.8	19.4	18.2	18.1	18.1	18.1
256	1/2	13.2	17.0	16.0	15.9	16.0	15.9
256	3/5	16.1	19.4	18.1	18.2	18.1	18.1
256	2/3	17.8	20.8	19.7	19.7	19.8	19.8
256	3/4	20.0	22.9	21.7	21.8	21.7	21.8
256	4/5	21.3	24.3	23.1	23.2	23.3	23.2
256	5/6	22.0	25.1	24.0	23.9	24.0	24.1

$^{\alpha}$ A correction factor for pilot boosting of 0.44 dB (PP4) or 0.33 dB (PP7) must be added.

The difference between simulations, corrected for pilot boosting, and measurements ranges from 0.8 to 2.2 dB (1.3 dB mean value). The rotation of the constellations, the GI duration and the PP have no significant influence in the results, as expected. These measurements can be used as a reference to evaluate the increase of the C/N_{min} due to multipath.

B. 0 dB Echo Channel

The DVB-T2 Implementation Guidelines [1] provide several channel models to be used as reference channels for different reception scenarios. One of those models, named "Simple two path profile, 0 dB Echo", is formed by two paths of equal amplitude, separated a time equivalent to 90% of the GI duration, with a frequecy shift of 1 Hz for the second path. This model has been used in many of the measuremets in this work. In Table III the measured C/N_{min} for this channel are presented together with the results from the simulated values provided by the Implementation Guideliness and the NorDig requirements for receivers. The DVB-T2 configuration is the default one (Table I) with the following changes:

TABLE III
SIMULATED AND MEASURED C/N_{min} FOR 0 dB ECHO CHANNEL

QAM	CR	Impl. Guid.$^{\alpha}$	NorDig	1/128 GIF, PP7 N.R	1/128 GIF, PP7 R	1/16 GIF, PP4 N.R	1/16 GIF, PP4 R
16	4/5	13.4	–	17.6	16.9	16.8	16.2
16	5/6	14.4	–	19.1	18.0	18.7	17.3
64	1/2	11.8	16.0	14.6	14.9	14.0	14.4
64	3/5	13.9	18.0	16.9	17.2	16.2	16.6
64	2/3	15.5	19.7	18.4	18.9	17.8	18.5
64	3/4	17.6	22.0	21.3	21.4	20.4	21.0
64	4/5	19.2	–	23.3	23.7	22.6	22.9
64	5/6	20.4	–	25.2	25.2	24.3	24.7
256	1/2	15.7	20.6	19.6	19.5	18.6	18.7
256	3/5	18.4	23.1	22.4	22.5	21.4	21.5
256	2/3	20.3	25.1	24.2	23.9	23.1	23.3
256	3/4	22.7	28.0	27.0	27.6	26.5	26.6
256	4/5	24.5	–	31.3	31.8	30.7	30.1
256	5/6	25.8	–	–	35.0	–	34.8

$^{\alpha}$ A correction factor for pilot boosting of 0.44 dB (PP4) or 0.33 dB (PP7) must be added.

- Constellations: 16, 64 and 256 QAM
- Rotated Constellations: Used and not used.
- Code rates: All code rates from 1/2 to 5/6 for 64 and 256 QAM. In the case of 16 QAM only the code rates that provide higher data rates (4/5 and 5/6) are tested.
- GIF and pilots patterns: 1/128, PP7 and 1/16, PP4.

Taken into account the correction factors for pilot boosting, Table III shows a difference between simulations and measurements of 2.1-8.5 dB with an average value of 3.3 dB.

C. Rotated Constellations

The use of rotated constellations is one of the new features of DVB-T2 [5]. This frequency diversity technique is intended to improve the reception when severe multipath is present, as in the case of 0 dB echo SFN. The use of rotated constellations is supposed to improve the performance of the system in different levels depending on the channel, from almost no gain for some channels, as Gaussian channel, to some dBs for severe multipath channels. A worse performance is not expected when using rotated constellations. The gain obtained by using rotated constellations depends also in the receiver implementation, but again the worst case for the simplest implementation is supposed to obtain the same performance whether the rotated constellations are used or not.

To test the influence of the rotated constellations the same DVB-T2 configurations as in previous section are used:

The parameters of the simulated channels are:

- Second path frequency shift: 0 and 1Hz
- Second path attenuation: 0 dB.
- Delay: 10%, 50% and 90% of the GI.

In total 6 channels have been tested.

The results are shown in Fig.1 where the gain of the rotated constellations (difference between the C/N_{min} for rotated and no rotated constellations) is plotted for each constellation and code rate. The mean values of the measurements for the six channel models have been used to draw the lines.

The results are as expected for 16 QAM where an important gain is obtained by using rotated constellations. The performance for 256 QAM, and especially for 64 QAM is not as predicted by the theoretic studies and simulations, because the gain of rotated constellations is negative, i.e. the C/N_{min} is increased when using this feature. The same performance is shown in all tested STB.

Gain for 256 QAM 5/6 is not plotted because when rotated constellations is not used the receivers never achieve the error free condition. When using rotated constellations the performance improves noticeably with C/N_{min} values in the range of 32 to 35 dB, so some gain is achieved in all the tested channels but can not be measured.

Because of this unexpected performance of the rotated constellations, in all the tested DVB-T2 configurations both options (rotated and not rotated constellations) will be used.

D. Second Path Delay

The objective of these measurements is to test the influence of the delay between first and second paths in a 0 dB echo SFN.

The default configuration parameters (Table I) have been used with the following changes:

- Constellations: 64 and 256 QAM
- Rotated Constellation: Used and Not Used.
- GIF and pilots patterns: 1/128, PP7 and 1/16, PP4.

The parameters of the simulated channels are:

- No frequency shift.
- Second path attenuation: 0 dB.

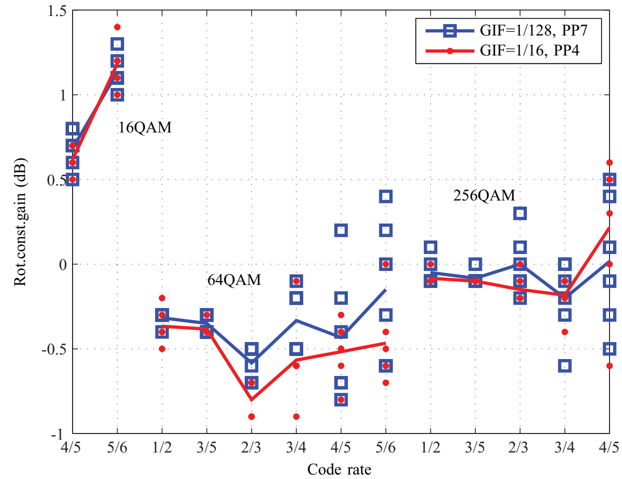


Fig. 1. C/N_{min} gain using rotated constellations

- Delay: From 1% IG to 110% IG.

The results are presented in Fig.2 for GIF 1/128 and 1/16. It must be considered that horizontal scales are the same for the fraction of the GI, but as the GI values are very different (28 and 224 μs), the times are also very different. A vertical dotted line has been used to mark the GI duration.

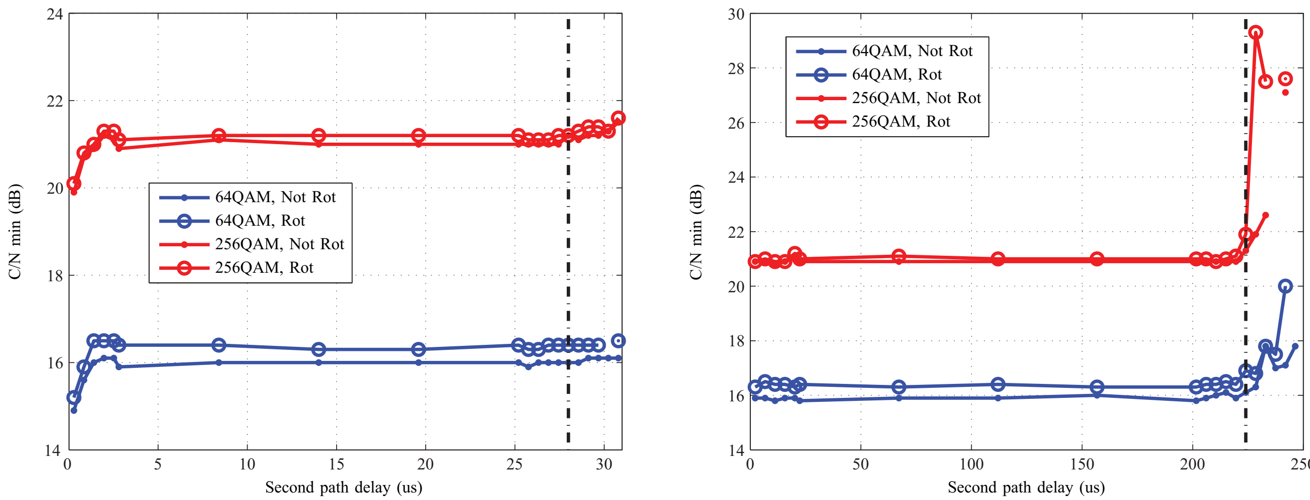
In Fig.2(a) the first measurement corresponds to only 0.28 μs. This short delay produces almost flat fading, and as the C/N value is adjusted to the actual generated power, the channel in this case is similar to Gaussian channel, that is why the C/N_{min} values are much lower.

When the delay spread increases the channel estimation and equalization becomes more and more difficult for the receiver. A denser pilot pattern used when large delays are expected (PP4) helps the receiver, so the performance is good for both configurations until the delay equals the GI. When the delay is longer than GI duration two effects are mixed. The error in the channel estimation is increased, and the second signal produces Inter Symbol Interference (ISI). The first effect depends on the ratio of the GI duration and the delay, whilst the second depends on the absolute value of the delay. In Fig.2(b) the last measurements corresponds to large delay spreads over the GI duration, in these cases a significant part of the OFDM symbol (0.6%) is interfered by the second signal, that is why the reception is severily impared, although the error of the channel estimation could still be low.

The missing points in the right part of the plots correspond to measurements where the error free condition is not reached.

E. Frequency Shift

This section studies the influence of a frequency shift in the second path. In a real SFN situation is not possible to have identical channel frequency in the transmitters of the network, so a frequency shift is present between the signals coming from different transmitters. In [1] 0 dB echo channel is defined with a frequency offset of 1 Hz. In many test performed for this work this value have been also used. To test the influence



(a) GIF=1/128, PP7 (b) GIF=1/16, PP4

Fig. 2. C/N_{min} vs second path delay

of the frequency shift, measurements have been taken from 0.1 Hz to 2.9 Hz in 0.2 Hz step. Measures for 0 Hz have also been included.

The DVB-T2 configurations are the same than in previous sections. The parameters of the simulated channel are:

- Second path delay: 50% GI.
- Second path attenuation: 0 dB and 3 dB.
- Frequency shift: From 0 to 2.9 Hz.

Results are displayed in Fig.3. As expected, the frequency shift increases the C/N_{min}. In the configuration with shorter GI (1/128) and 256 QAM the increase in the frequency shift affects more rapidly to the C/N_{min}. For 0 dB echo, with only 1 Hz the C/N_{min} increases about 1.5 dB and for 3 dB echo at 1 Hz the measured C/N_{min} is similar to 0 dB echo with no frequency shift.

F. Second Path Attenuation

The influence of the SFN in the reception quality is mainly affected by the relative attenuation between the main and the second path. In this section the influence of this parameter is tested. The influence of the relative position of the strongest path it is also tested, so pre-echo and post-echo scenarios are simulated.

The default DVB-T2 configuration is used with these modifications:

- Constellations: 64 and 256 QAM
- Code rates: All code rates from 1/2 to 5/6.
- GIF and pilots patterns: 1/128, PP7 and 1/16, PP4.
- Rotated constellations: Used and not used.

The parameters of the simulated channels are:

- Second path delay: 50% GI.
- Second path attenuation: 0 dB and from -15 dB (pre-echo) to +15 dB (post-echo) in 2 dB step.
- Frequency shift: 0 Hz.

Fig.4 represent the measured C/N_{min} versus the relative amplitude of the paths for all tested configurations. The code rate is placed near the corresponding curve.

The C/N_{min} increases for lower attenuation levels and consequently the 0 dB echo is the worst case. The increment is larger for the configurations with higher code rate like 4/5 and 5/6. Two cases of particular interest are 64 QAM 4/5 compared with 256 QAM 3/5, and 64 QAM 3/4 compared with 256 QAM 1/2. These configurations provide the same bit rate but the C/N_{min} is different. For 256 1/2, and 64 3/4, the 64 QAM option is better for any relative attenuation if rotated constellations is not used in 64 QAM. For 256 3/5 and 64 4/5, the 64 QAM option is better for low multipath channels, but the C/N_{min} increases faster and at 3 dB echo both options performs equal, and at 0 dB echo 256 QAM is clearly better.

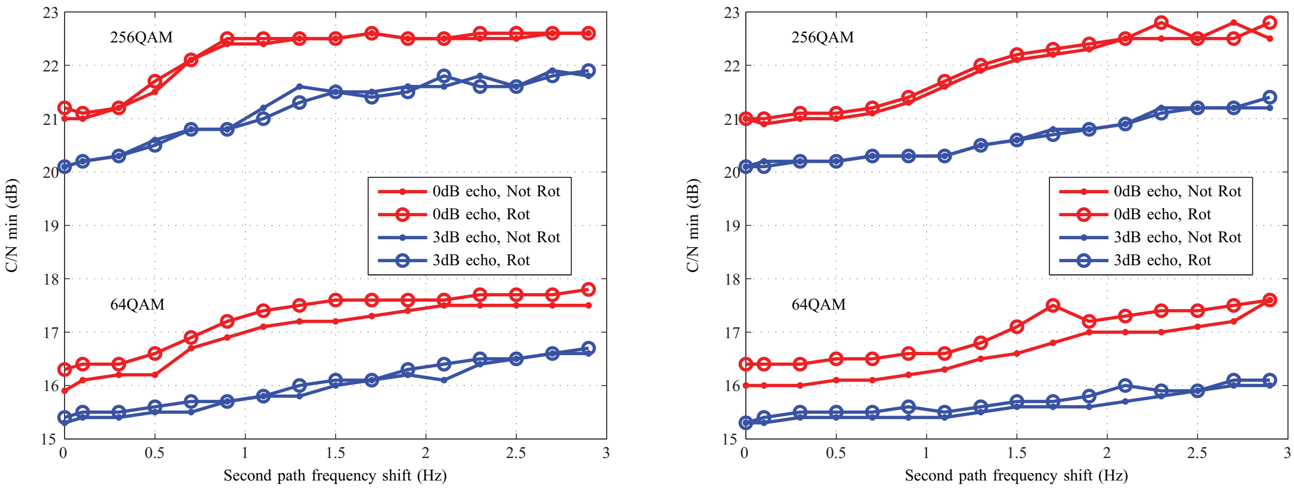
The type of multipath, pre-echo or post-echo, has little influence when short GI is used, but when long GI is used pre-echo multipath impairs more deeply the reception of the signal, specially for 256 QAM 4/5 and 5/6.

These figures are useful to observe the influence of the rotated constellations. In general, only when 0 dB echo is present the positive or negative gain is noticeable.

G. Pilot Pattern

Once the GI duration has been chosen according to the maximum delay spread expected, it is necessary to choose the PP from the options allowed. To test this configuration parameter a GIF of 19/256 has been selected because several reasons:

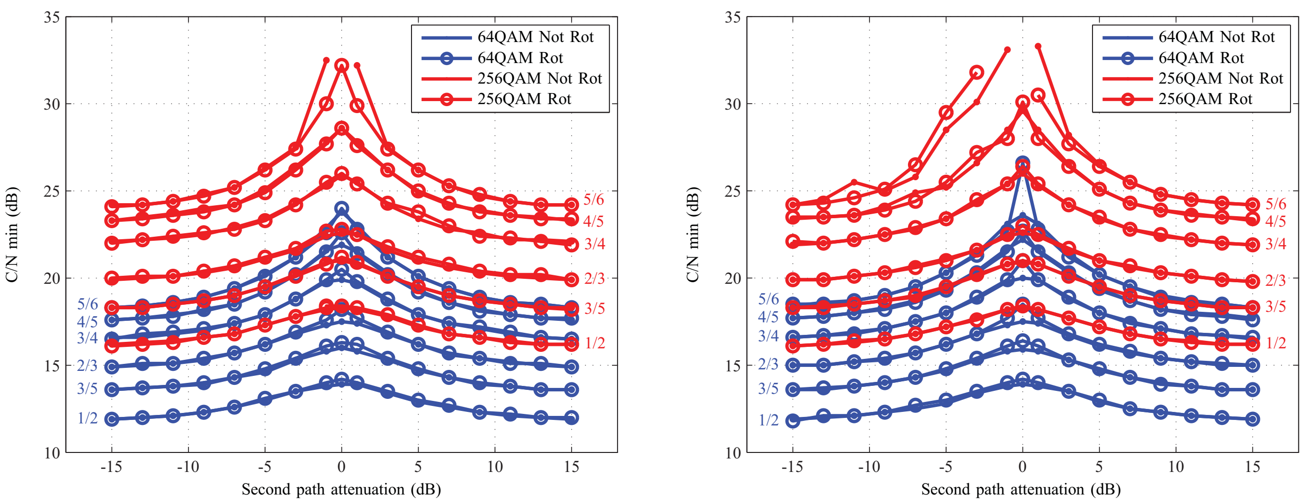
- It allows several PP options.
- The time-with of the channel is 89% of the Nyquist limit, which is longer than for other GIF options (75%).
- For 32K the GI duration is 266 μs which is similar to the GI duration corresponding to 1/16 (224 μs) used for



(a) GIF=1/128, PP7

(b) GIF=1/16, PP4

Fig. 3. C/N_{min} vs frequency shift



(a) GIF=1/128, PP7

(b) GIF=1/16, PP4

Fig. 4. C/N_{min} vs relative amplitude of the paths

many measurements of this study.

The changes in the default configuration are:

- GIF: 19/256.
- FFT size and PP: 8K (PP4, PP5 and PP8), 16K (PP2, PP4, PP5 and PP8), 32K (PP2, PP4 and PP8).
- Rotated constellations: Used and not used.

The parameters of the simulated channels are:

- Second path delay: 50%, 90%, 95%, 100% and 110 % of GI.
- Second path attenuation: 0 dB and 3 dB.
- Frequency shift: 0 and 1 Hz.

Tables IV, V and VI show the obtained C/N_{min} for 8K, 16K and 32K.

The simulated channel is static, so the time repetition pattern of the scattered pilots should not have any influence in the results. For example, PP4 and PP5 have the same frequency pattern, but PP4 is two times denser in time and the results are very similar for both. On the other side, PP2 and PP4 have the same time pattern, but PP2 doubles the number of pilots in frequency, that is why PP2 performs better for large delay spread.

PP8 is a special pattern intended to be used with CD3 [1]. It should also work well for static channels, as in this case, but clearly for 32K, when the OFDM symbol is the longest one, the performance according to the results is really poor.

VI. Conclusions

The presence of multipath means higher C/N minimum requirements compared with Gaussian channel. The 0 dB echo channel is a big impairment for the reception of the DVB-T2 signal, but fortunately very unusual with rooftop antenna

TABLE IV
C/N MIN 8K

PP	Att dB	Shift Hz	Path delay (%GI)									
			50%		90%		95%		100%		110%	
			N.R	R	N.R	R	N.R	R	N.R	R	N.R	R
4	0	0	20.8	21.0	21.6	21.7	–	–	–	–	–	–
5	0	0	20.9	21.0	22.0	22.0	–	–	–	–	–	–
8	0	0	21.2	21.2	22.4	22.7	21.8	22.3	21.5	21.5	–	–
4	0	1	21.2	21.3	21.6	21.8	–	–	–	–	–	–
5	0	1	21.5	21.5	21.8	21.8	–	–	–	–	–	–
8	0	1	23.1	23.0	23.1	23.1	22.9	23.0	23.2	23.2	–	–
4	3	0	19.9	19.9	20.4	20.5	30.9	30.6	–	–	–	–
5	3	0	20.0	20.0	20.6	20.5	30.3	30.0	–	–	–	–
8	3	0	20.3	20.3	20.2	20.5	20.3	20.3	20.4	20.3	23.2	23.4
4	3	1	20.2	20.3	20.6	20.7	31.1	30.9	–	–	–	–
5	3	1	20.2	20.2	20.6	20.6	31.3	31.0	–	–	–	–
8	3	1	21.0	21.0	21.2	20.9	21.1	20.9	21.2	21.0	24.6	24.7

TABLE V
C/N MIN 16K

PP	Att dB	Shift Hz	Path delay (%GI)									
			50%		90%		95%		100%		110%	
			N.R	R	N.R	R	N.R	R	N.R	R	N.R	R
2	0	0	20.8	20.9	20.8	20.9	20.8	20.9	20.9	21.2	27.6	28.5
4	0	0	20.8	20.9	21.5	21.6	–	–	–	–	–	–
5	0	0	21.0	21.1	21.7	21.7	–	–	–	–	–	–
8	0	0	21.4	21.4	21.8	21.8	21.2	21.2	21.6	21.5	30.7	30.9
2	0	1	21.2	21.3	21.2	21.3	21.2	21.3	21.4	21.5	29.5	30.8
4	0	1	21.0	21.2	21.5	21.6	–	–	–	–	–	–
5	0	1	21.7	21.7	22.0	22.0	–	–	–	–	–	–
8	0	1	22.8	22.9	22.9	22.9	23.0	22.9	23.1	23.0	–	–
2	3	0	19.9	19.9	19.9	20.0	20.0	20.0	20.2	20.1	22.6	22.7
4	3	0	20.0	20.0	20.5	20.5	31.1	31.3	–	–	–	–
5	3	0	20.0	20.0	20.5	20.5	30.3	30.2	–	–	–	–
8	3	0	20.5	20.6	20.5	20.2	20.4	20.6	20.5	20.4	23.2	23.3
2	3	1	20.3	20.3	20.3	20.3	20.3	20.3	20.4	20.4	23.2	23.1
4	3	1	20.2	20.2	20.6	20.6	31.0	30.8	–	–	–	–
5	3	1	20.3	20.3	20.8	20.7	33.0	31.9	–	–	–	–
8	3	1	22.1	22.1	22.3	22.3	23.2	23.1	22.3	22.2	28.0	27.8

reception. This standard provides some features to improve the reception in such conditions, but the gain obtained with those features is not always as big as expected (some times negative) it and could largely depend on the receiver implementation. For example, more measurements should be performed to analyze the performance of 64 QAM in combination with rotated constellations using other different receivers, as it is very likely that all the tested STBs use the same DVB-T2 decoder chip-set.

The values presented here can be used as a guide to help broadcasters and regulatory bodies to choose the DVB-T2 parameters for several receptions scenarios and to estimate the C/N_{min} to be used for network planning.

TABLE VI
C/N MIN 32K

PP	Att dB	Shift Hz	Path delay (%GI)									
			50%		90%		95%		100%		110%	
			N.R	R	N.R	R	N.R	R	N.R	R	N.R	R
2	0	0	21.1	21.1	25.1	29.0	22.9	–	–	21.7	–	–
4	0	0	20.9	21.0	21.5	21.7	–	–	–	–	–	–
8	0	0	23.8	22.8	–	24.9	26.2	–	–	–	–	–
2	0	1	21.4	21.6	24.3	21.5	27.2	21.9	23.9	23.9	–	–
4	0	1	21.5	21.6	21.6	21.7	–	–	–	–	–	–
8	0	1	–	–	–	–	–	–	–	–	–	–
2	3	0	20.3	20.3	20.2	20.3	20.3	20.2	20.3	20.3	–	–
4	3	0	20.2	20.2	20.6	20.7	–	–	–	–	–	–
8	3	0	22.4	21.2	21.6	21.6	21.1	22.2	24.0	22.0	–	–
2	3	1	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	–	25.5
4	3	1	20.3	20.3	20.8	20.9	–	–	–	–	–	–
8	3	1	–	–	–	–	–	–	–	–	–	–

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