HDTV field trials using DVB-T and DVB-T2 broadcasting systems

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***Abstract*—This paper presents the first field trials carried out in Spain to test HDTV reception using DVB-T and DVB-T2 systems. High definition and standard definition digital television contents and services were multiplexed and broadcasted from a terrestrial transmitter.**

The aim of these trials was to analyze DVB-T2 technology when this system is configured according to the needs of terrestrial HDTV broadcasting and to compare the results with DVB-T technology in terms of CNR requirements and achieved data rate.

Field measurements were carried out in different scenarios and reception conditions. The study presented in this paper is focused on fixed reception, Gaussian channel, because it is the expected reception condition for HDTV.

***Index Terms*—DVB-T2, DVB-T, HDTV, Digital Terrestrial Television, Field Trials.**

I. Introduction

In June 2008, European DVB project finalized the DVB-T2 specification and in September 2009 ETSI released the first version of the standard [1]. DVB-T2 is the most advanced terrestrial broadcasting system, designed for use after Analogue Switch-Off. It introduces some technical enhancements in comparison with its predecessor DVB-T [2], including better modulation and coding techniques to increase system capacity and robustness, enabling more spectral efficiency to deliver digital services to different reception scenarios. DVB-T2 is not intended to replace DVB-T for Standard Definition Television (SDTV) broadcasting. The main driver for DVB-T2 will be primarily, but not exclusively, the broadcast of High Definition Television (HDTV) over terrestrial networks.

Field trials are required to check HDTV broadcasting using this new technology, comparing simulations and laboratory results [3] with field reception in real scenarios. They are also very interesting for testing and validating DVB-T2 equipment prototypes that are currently under development.

Even having lower multiplex capacity and requiring higher Carrier to Noise Ratio (CNR) values, DVB-T technology can also be used to broadcast HDTV services. These field trials also aim to compare both technologies for HDTV broadcasting, considering several configuration modes.

II. Methodology

A. Configuration Modes

Television services are coded using MPEG-4 (High_Profile@Level4) for HD contents and using MPEG-2 (High_Profile@MainLevel) for SD contents [4]. The bit rate for each HD program ranges from 8 to 16 Mbps depending on the HD type and whether statistical multiplexing is used or not. The achieved bit rate for one multiplex is a key factor for the broadcasters to be able to accommodate as many programs as possible.

TABLE I
DVB-T2 Transmitted Modes

Mode Number	1	2	3	4	5	6
Standard	T	T	T2	T2	T2	T2
FFT size	8K	8K	32K	32K	8K	8K
GI	1/4	1/4	1/128	1/128	1/32	1/32
QAM	64	64	256	256	256	64
Rotated	-	-	No	Yes	Yes	Yes
Code rate	2/3	3/4	3/5	3/5	3/5	3/4
bit rate (Mbps)	19.9	22.4	36.1	36.1	35.3	33.0
CNR (dB) (AWGN)	16.5	18.0	16.0	16.0	16.0	15.1

DVB-T2 system has many configuration options that allow the system to be used for different broadcasting scenarios, from low resolution handheld receivers, to large screen HDTV sets. This study is focused on HDTV, so the tested configurations are chosen to provide high bit rates and to be received with roof top directive antennas.

In these trials six configuration modes are used, two with DVB-T technology and four with DVB-T2 technology. Table I shows main features of these modes and the CNR required according to simulations.

- Mode 1 is the DVB-T reference mode to test. It is the mode currently used in Digital Terrestrial Television in Spain.
- Mode 2 is a DVB-T mode with higher bit rate that could be more suitable to broadcast HDTV but at expenses of worse coverage.
- Mode 3 could be the most suitable mode for future HDTV broadcasting networks with fixed reception.
- Mode 4 is similar to Mode 3, but rotated constellations are used. This way the performance of this new feature

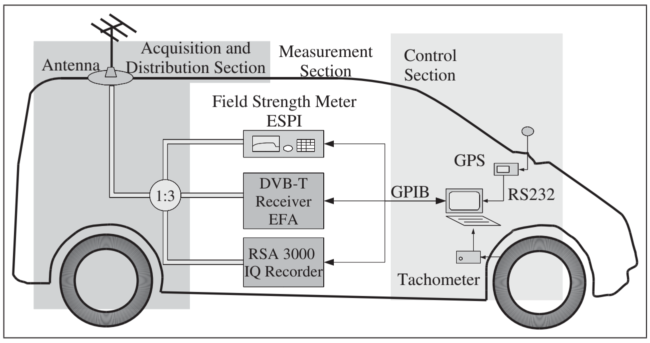

Fig. 1. Measurement system

of DVB-T2 can be evaluated.
- Mode 6 is the most similar to the DVB-T modes, and can be used to compare DVB-T2 and DVB-T transmissions, testing CNR improvements due to Low Density Parity Check (LDPC) plus BCH codes in comparison to convolutional plus Reed Solomon (R-S) codes.
- Modes 5 and 6 can be compared to test the influence of different order constellations in system performance.
- Comparison between Modes 3-4 and Mode 5 will show the influence of the OFDM symbol size on the CNR requirements.

All DVB-T2 modes have the following common parameters:
- 8 MHz Extended Mode.
- PP7 pilot pattern.
- Normal Forward Error Correction (FEC) frame length (64,800 bits).
- One Physical Layer Pipe (PLP).

B. Measurement system

Several parameters were measured during the field trials to be able to perform a deep analysis of the broadcasting systems:
- Received Radio Signal Strength (RSSI) and Carrier to Noise Ratio (CNR).
- Received Signal Spectrum.
- Constellation MER.
- BER (after Viterbi decoder in DVB-T, and after LDPC decoder in DVB-T2).
- Channel Impulse Response and Channel Transfer Function (provided by equalization stage in receiver).
- IQ samples of incoming signals, recorded for further off-line analysis.

The whole measurement system was installed in a mobile unit with autonomous power gear and hydraulic mast that raises antenna up to 8 meters. The antenna used for reception was a directive Uda-Yagi antenna (15.5 dBi gain). The measurement system is represented in Fig.1.

DVB-T measurements were carried out with one professional test-receiver. This receiver can add noise to the received DVB-T signal to obtain the BER after Viterbi versus CNR plot, which is used to calculate the required CNR for the Quasi-Error-Free (QEF) after R-S, condition that corresponds to $2 \cdot 10^{-4}$ BER after Viterbi.

At the time of the measurement campaign there were no professional DVB-T2 test receivers available in the market. To solve this problem DVB-T2 measurements were carried out in two ways:

1) A DVB-T2 receiver prototype was used to check that the received signal was a proper DVB-T2 signal and to take some basic measurements.
2) The received signal was recorded with a signal analyzer for latter off-line processing. This method did not provide on-line measurements (that was the reason for using the receiver prototype), but allowed deep analysis of the received signal. The signal analyzer could record up to 5 seconds of signal, at a sampling frequency of 12.8 MHz, which is suitable for the usual DVB-T2 bandwidth. Five seconds of signal ensure at least 20 DVB-T2 frames for the measured configurations.

C. DVB-T2 signal processing

The QEF condition threshold is set to 10^{-7} for BER after LDPC in [3]. To obtain the CNR that corresponds to that condition BER versus CNR plot was first obtained.

A DVB-T2 receiver software implementation has been developed for signal analysis by TSR research group of the University of the Basque Country. This program implements the whole reception chain, from synchronization to PLP extraction, and provides detailed measurements of the main parameters of the recorded signal such as MER, channel Frequency Response, channel Impulse Response and BER at several steps of the reception chain.

The program also computes the signal power and adds Gaussian noise in order to achieve the desired CNR level. This feature was used to obtain BER-CNR plots.

The signals selected for this study correspond to a measurement point that fulfills the following requirements:
- Gaussian channel. The available simulations in [3] are for this kind of channel, so this allows direct comparison between measurements and simulations. Directive rooftop antennas are expected to be used for HDTV reception, so the propagation channel will be Gaussian or Ricean.
- Signal level good enough to have MER about 30 dB. This is necessary to ensure that the added noise is the main noise contribution to the CNR.
- BER before BCH is 0. This allows receiving the bits with no errors and using them to be compared with the decoded bits when noise is added and errors are detected, but can not be corrected by the BCH decoder. With this procedure real BER is measured, even for low CNR levels, like when a PRBS is transmitted for this purpose.
- Measurements available for all modes at the selected location (as explained latter not all modes were measured at all locations)

Once the optimum point was selected, BER vs. CNR graph was plotted and the CNR threshold value for correct reception was obtained. Five second of recorded signal provide between $1.6 \cdot 10^8$ and $1.8 \cdot 10^8$ of received bits after LDPC decoder

Fig. 2. Valencina broadcasting center transmission towers

Fig. 3. Sevilla map with place marks at all measurement locations, selected location for the study and Valencina transmission station

depending on the mode. The exact amount of received bits can also vary slightly depending on the signal sample where the first DVB-T2 frame is received, because the receiver program needs the first symbol of the frame (P1 symbol) to begin the synchronization procedure and the samples before it must be discarded. These figures lead to floor value for measured BER of $6 \cdot 10^{-9}$. In this study when the obtained BER was 0 the floor value was used instead.

D. Transmission network and reception scenarios

Valencina transmission center was used to cover the city of Seville. Valencina is located on a hill about 8 km far from the city center and 160 m higher. In Fig.2 the transmission towers of the centre are shown.

The transmission equipment for DVB-T2 (modes 3-6) consisted on:

- A DVB-T2 modulator that generated the signal at Intermediate Frequency (IF). This device could be controlled remotely by means of a Web-based interface. This feature was used to change the configuration options of the system.
- A frequency converter and amplifier that shifted the IF signal to the channel frequency 594 MHz and amplified it to achieve the sufficient level to input the power amplifiers.
- Four power amplifiers that provided the final 480 W.
- The radiating system: Two panel array with 15.6 dBi maximum gain.

For DVB-T (modes 1-2) two different transmission systems were used:

1) The DVB-T transmission system located in the same center used to broadcast the Digital Terrestrial TV (DTT) Spanish public TV programs at 762 MHz. This transmission corresponds to mode 1 and, as it is a commercial broadcasting, the configuration could not be changed.
2) The same transmission system used for DVB-T2 but using a DVB-T modulator. In this case the configuration could be changed to mode 1 or 2.

Field measurements were carried out in fixed reception for urban, suburban and rural environments. There are 30 different measurement locations for mode 1 and modes 3, 4 and 5. At each location all the modes were measured sequentially, first mode 1 at 762 MHz, and after that DVB-T2 modes at 594 MHz. To change the modulator configuration a link was established between the mobile unit and the transmission center by means of the UMTS/GPRS network and a virtual private network (VPN) connection. The main advantage of this method is that all DVB-T2 modes were measured in the same reception conditions, like mobile unit location, antenna orientation or environment conditions, which allows direct comparison between all DVB-T2 modes. Other advantage was the time saving, so measurements could be taken at more locations for the same measurement campaign duration. The main disadvantage was that mode 1 (DVB-T) was measured at a different frequency, so the propagation channel could be slightly different.

Mode 2 was measured in fewer locations (8) because, as explained before, it was not possible to change the DVB-T commercial emission settings. To measure mode 2 and mode 1 at 594 MHz the transmission equipment setup was changed and the mobile unit was placed at locations where DVB-T2 measurements were previously taken.

The measurement locations are shown in the map of Fig.3. White place marks correspond to locations where mode 2 was not measured and yellow place marks corresponds to locations where measurements for all the modes are available. Valencina transmission station is represented too.

The location selected to perform the CNR requirements study is labeled in Fig.3 as *Selected Point*. This point is located 8.4 km far from the transmitter center, in a residential area of Seville, in a suburban environment. Fig.4 is a picture of the mobile unit at this location.

The spectrum of the DVB-T2 received signal is represented in Fig.5. The standard deviation of the spectral amplitudes

Fig. 4. Mobile unit at the selected measurement location

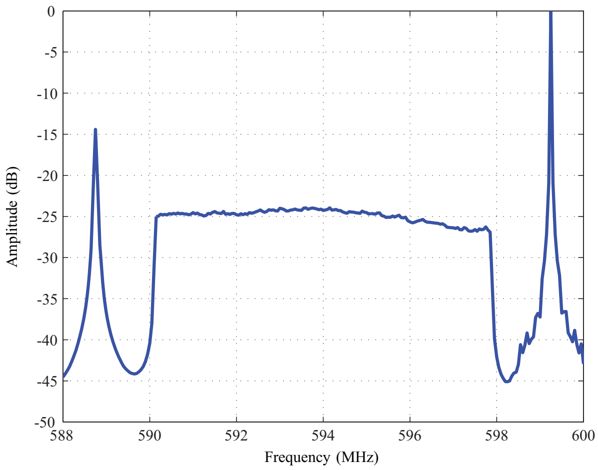

Fig. 5. Spectrum of DVB-T2 selected signal

of the signal ($\sigma = 0.7 < 1$) has been used to classify the propagation channel as Gaussian [5]. Together with the signal two unwanted adjacent analog TV channels were present as shown in the figure.

III. Results

In Fig.6 BER before BCH (after LDPC) is represented for a range of CNR values. Each line corresponds to a different DVB-T2 mode, all of them measured in the point selected according to criteria explained in section II. The red dusted line indicates the BER limit threshold value for a QEF reception. The lower flat part of the lines indicates that the whole signal was processed and no errors were present so BER was 0 at the corresponding CNR levels. The BER floor value has been used to indicate that condition.

It should be remarked the sharp fall of the BER around the threshold value for all modes. In a range of 0.2 dB (mode 6) or 0.4 dB (modes 3, 4 and 5) BER falls from 10^{-2} to 10^{-7}. This behavior is consequence of the use of the LDPC FEC and the

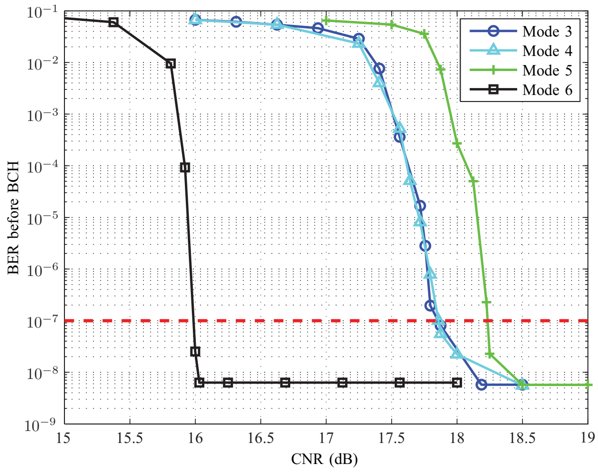

Fig. 6. BER vs. CNR plot for the selected point

number of iterations performed to decode the received bits. In the developed software receiver this number is set to 50, as recommended in [3]. The results of simulations presented in [3] are similar to the plots obtained from these measurements.

In table II the measured threshold values for all the modes are presented together with the simulated performance of these modes according to [2] and [3].

The DVB-T2 results shown in Fig.6 and in table II are especially good for mode 6. In this case the CNR requirement according to measurements is only 0.9 dB higher than the requirement according to simulations. In the case of modes 3 and 4 the difference rises up to 1.9 dB. The worst case is mode 5 with 2.2 dB higher CNR requirement than the expected.

Modes 3 and 4 have similar performance. The difference between them is that mode 4 uses rotated constellations, a new feature included in DVB-T2 that is intended to improve the robustness of the system when deep frequency selective fading is present. The studied case is Gaussian channel and it is logical that rotated constellations have no influence in the results.

The performance of mode 5 was expected to be the same as modes 3 and 4 because the main difference between them is the FFT size. Further research will be needed to find out the reasons for this behavior.

The 64 QAM mode (mode 6) performs better than 256 QAM modes (about 2 dB) with the coding rates chosen to provide similar bit rates, less protected for 64 QAM (3/4) and more protected for 256 QAM (3/5). The difference between these modes is about 1 dB higher than expected according to simulations [3] and it is important enough to consider the convenience of using 256 QAM constellations.

As the use of higher order constellations forces LDPC FEC to correct larger number of errors, the improvement of the LDPC decoding could improve the 256 QAM constellation performance. One possible modification to be tested is the use of iterative demapping together with iterative LDPC decoding as suggested in [3].

TABLE II
RESULTS

	DVB-T		DVB-T2			
Mode	1	2	3	4	5	6
CNR (Imp.Guide.)	16.5	18.0	16.0	16.0	16.0	15.1
CNR (Measur.)	17.4	19.1	17.9	17.9	18.2	16.0

Modes 2 and 6 be can used to compare DVB-T and DVB-T2. Both modes have similar configuration including 8K FFT size, 64 QAM and 3/4 coding rate. The main difference between them is GI, which in Gaussian channel should not have more influence than the reduction of bit rate as GI increases. According to the measurements the CNR requirements for mode 2 is 3.1 dB higher than for mode 6. This difference is caused by the use of LDPC FEC coding that enhances the system performance compared with the use convolutional plus R-S codes.

Together with the lower CNR requirement DVB-T2 provides higher data rate. If mode 6 were configured with the same 1/4 GI as modes 1 and 2, the bit rate would be 25.5 Mbps which is 13% higher than the bit rate of mode 2 and 28% higher than the bit rate of mode 1 (and with lower CNR requirements).

If mode 3 or 4 are chosen to substitute mode 1, that is used in many countries like in Spain, bit rate will increase 66% from 19.9 Mbps to 33.2 Mbps (for the same GI length), with only 0.5 dB increase in CNR requirement.

Four HDTV programs could be fitted in a multiplex with a bit rate of 33.2 Mbps if statistical multiplexing is used [4], or four SD programs plus one HD program with low compression video coding.

IV. CONCLUSIONS

The results of these field trials have shown the good performance of DVB-T2 system for the conditions in which terrestrial HDTV is expected to be received in many countries like Spain, that is, roof-top directive antenna.

Although both DVB-T and DVB-T2 technologies could be used for HDTV broadcasting, DVB-T offers lower capacity and if the present configuration parameters are changed to increase the available bit rate the CNR requirement would increase too.

DVB-T2 includes the latest improvements in signal processing coding and modulation and it is completely configurable to achieve the required bits rates for HDTV broadcasting with CNR requirements similar to the ones of the present DVB-T transmissions.

Finally, the results presented here validate the simulations and laboratory tests performed so long, and can serve as reference for network planning and receivers design. These results should be updated with the results of processing every measurement from all locations.

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